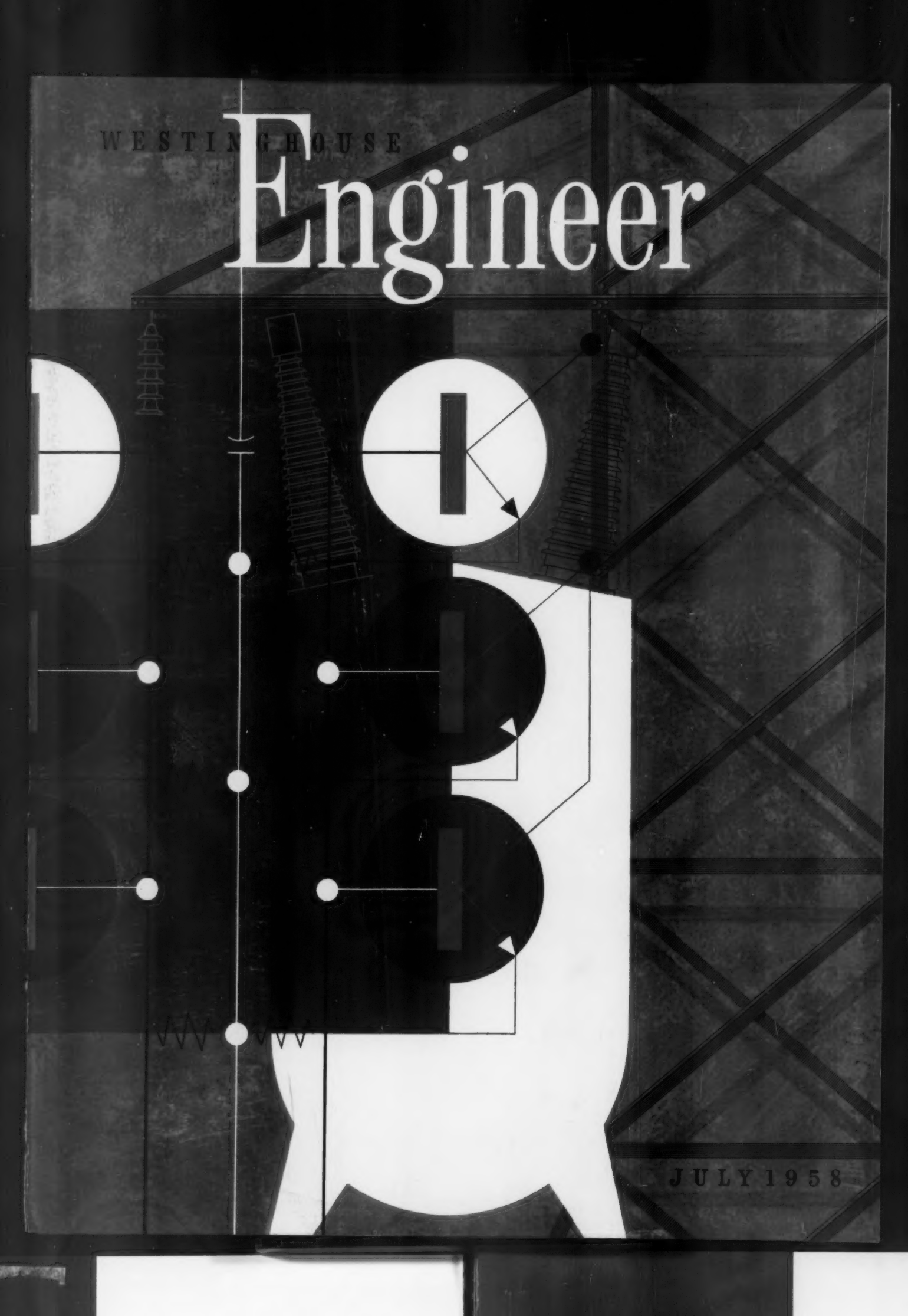
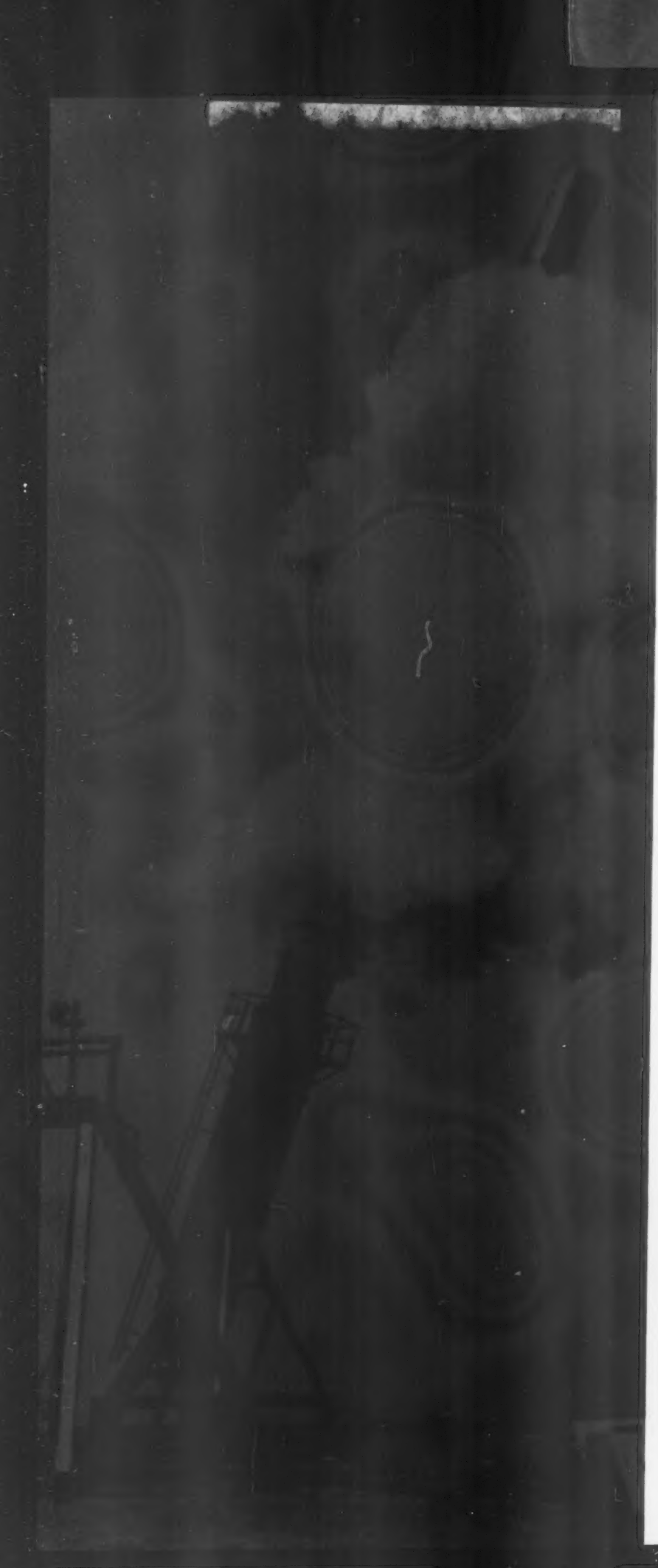

WESTINGHOUSE
Engineer
JULY 1958



POLARIS "peashooter"

A key step toward placing the U. S. Navy's *Polaris* missile into service has been completed on the West Coast, where missile-launching equipment designed and developed by Westinghouse recently underwent its first tests by completing numerous firings of dummy missiles.

The trial firings—labeled "Operation Peashooter"—were made from the Company's experimental test installation at the San Francisco Naval Shipyard. Some of the mock-up missiles (see photograph) are constructed of redwood, which floats in water and simplifies recovery. The method used is one of several launching techniques investigated by Westinghouse scientists and is similar to the launching of aircraft from Navy carriers. Instruments inside launcher and test vehicles disclose speeds, temperatures, stresses, and other technical data vital to missile launch studies. Underwater tests are underway at other experimental sites.

Polaris, a fleet ballistic missile, is being designed to be launched from above or below the surface of the water. The nation's first ballistic missile to be assigned to specially equipped naval ships, it will be capable of carrying a thermonuclear warhead.

The *Polaris* missile, with its range of 1500 miles, will have flexibility and mobility unique to naval operations and will extend the nation's defense perimeter to greater distances.

COVER DESIGN: Transistorized power-line carrier is the subject of this month's cover design by the R. G. Marsh Studios. A portion of transistor circuitry, a circuit breaker, and a transmission tower are the key elements chosen to symbolize the subject.

RICHARD W. DODGE, *editor*
MATT MATTHEWS, *managing editor*
DANIEL E. UDELL, *assistant editor*
EDWARD X. REDINGS, *design and production*
J. A. HUTCHESON, J. H. JEWELL, DALE MCFEATTERS, *editorial advisors*

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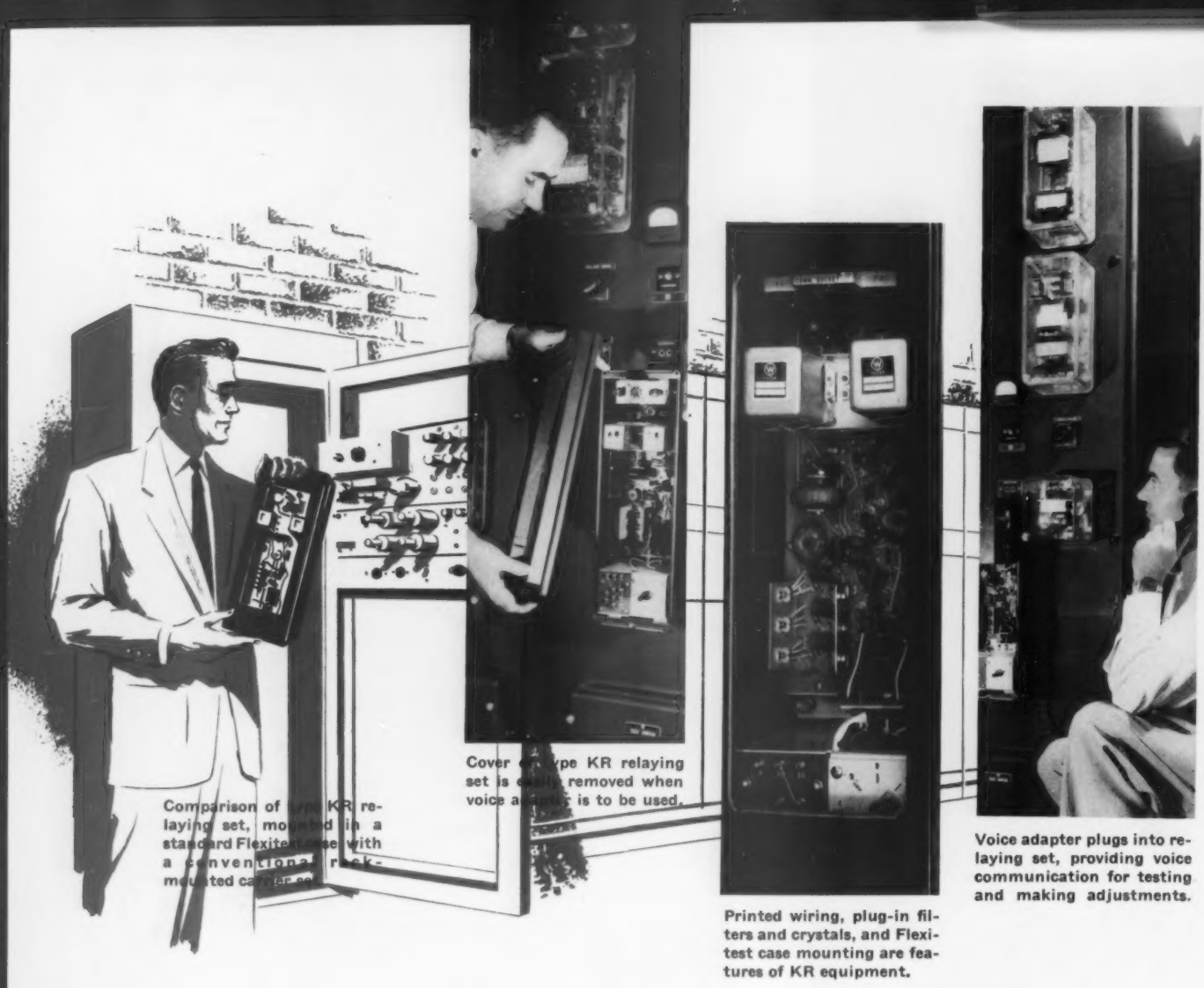


Comparison of type KR relaying set, mounted in a standard Flexitest case with a conventional rack-mounted carrier set.

Cover of type KR relaying set is easily removed when voice adapter is to be used.

Printed wiring, plug-in filters and crystals, and Flexitest case mounting are features of KR equipment.

Voice adapter plugs into relaying set, providing voice communication for testing and making adjustments.

modernizing power-line carrier with transistors

E. E. SCHENEMAN, Carrier Microwave Department, Westinghouse Electric Corporation, Halethorpe, Maryland

Designers of power-line carrier equipment saw in the transistor a means for improving reliability, minimizing maintenance, and reducing power and space requirements of carrier apparatus.

A prime objective of electric utilities is uninterrupted electric power for their customers. Power-line carrier equipment used in conjunction with protective relays has long helped provide this uninterrupted service. Recently developed type KR carrier-relaying equipment, which uses transistors in place of vacuum tubes, is a step forward in improved carrier-relaying reliability under regular service conditions.

The extremely long life, small size, and low power requirements of transistors result in a number of advantages for power-line carrier equipment. Maintenance cost is reduced by eliminating vacuum-tube replacements. Floor space is saved, since the set is housed in a Flexitest relay case that can be mounted directly on the switchboard. When the carrier set is mounted on the same panel with the relays, external wiring is simplified. Battery and battery-charger requirements can be reduced with transistorized equipment; equivalent tube relaying sets require approximately 250 watts as compared to 25 watts for the transistorized set.

distance relaying

The primary function of the type KR relaying set, together with modern protective relays, is to provide reliable high-speed simultaneous breaker tripping at both ends of a faulted transmission line section, or prevent tripping when

the fault is in another line section. The rapid isolation of a faulted line section reduces the possibility of damage to other equipment, and improves service continuity.

The operation of KR relaying assemblies in conjunction with directional-distance relays is shown in Fig. 1. The relays, operating from potential and current transformers on the power line, detect and determine direction of current flow. If a fault occurs *outside* the line section being protected, fault power flows out one end of the line, indicating to the protective relays that the breakers should not be tripped. The relays start the carrier transmitter, and a *hold* signal is sent to the remote carrier receiver. At the remote end, power is flowing into the protected line section, so that to the remote relays the fault appears in the line section. The remote relays would therefore act to open the circuit breaker, but upon receiving the carrier hold signal, the remote receiver prevents the trip coil from operating, keeping the remote circuit breaker closed.

If the fault is *inside* the protected line section, fault power flows into the section from both ends. The protective relays at each end stop the carrier transmitters from operating. Since the receivers get no blocking signal, the protective relays can operate the breaker trip coils.

Carrier transmitters and receivers usually operate on the same frequency, but different frequencies for transmission and reception can be used. Since carrier is transmitted for blocking purposes only, it is not needed or used on the line section that is actually faulted.

In single carrier frequency systems, the output of the transmitter is picked up by both carrier receivers, and tripping is blocked at both terminals. The receiver at the end where fault current is flowing out of the section will not receive a blocking signal in the two-frequency system, but the relay directional element contact will prevent tripping.

The operating speed of a carrier system is a function of bandwidth of the complete channel. The narrower the bandwidth, the longer the signal tends to "hang on," which in turn causes the relay to "hang on," resulting in slower operating speeds. However, narrow bandwidths make possible closer spacing between channels, and hence more channels. Type KR relaying has been designed as an optimum compromise between these two conflicting requirements, providing the necessary bandwidth for modern high-speed relaying, Fig. 2. (With transmission-line sections trapped at each end, and with properly tuned line-coupling units, the transmission line itself usually offers no appreciable bandwidth restriction.)

The frequency range of the relaying set is 30 to 200 kc. The frequency is easily changed by replacing the front-end receiver filter, both oscillator crystals, and retuning the transmitter output filter. Oscillator frequency remains within 0.01 percent through a temperature range of −20 degrees C to +50 degrees C with simultaneous voltage variations from 100 volts to 140 volts d-c.

Under standard conditions (129-volt d-c supply and 120-kc carrier frequency) the transmitter has a power output of 1.2 watts and the receiver has a sensitivity of 40 millivolts.

secondary functions

The carrier assemblies for relaying can also be used for telemetering, supervisory control, or both, with or without relaying. Relaying signals have precedence over all others; supervisory control signals take precedence over selective telemetering signals. As in the case of relaying, supervisory control does not require continuous signal transmission. Therefore, combinations of other services with supervisory control is quite logical. These other services can include practically any function that requires a channel that can be keyed *on-off*.

Sleet Detection—The equipment is also designed so that measurements can be made at a remote point, such as a switchboard, by means of a sleet-detector unit and switchboard milliammeter. This test is actually a reserve signal test, which in effect measures changes in channel attenuation. Since accumulation of sleet on a transmission line causes attenuation at carrier frequencies, observation of sleet and measurements of attenuation give data for calculating the amount of sleet formation on a particular line. During sleet conditions, frequent attenuation checks will warn of sleet formation and permit remedial action before the transmission line is damaged.

Normally, a carrier-relaying receiver operates so that relatively wide variations in input signal can be tolerated

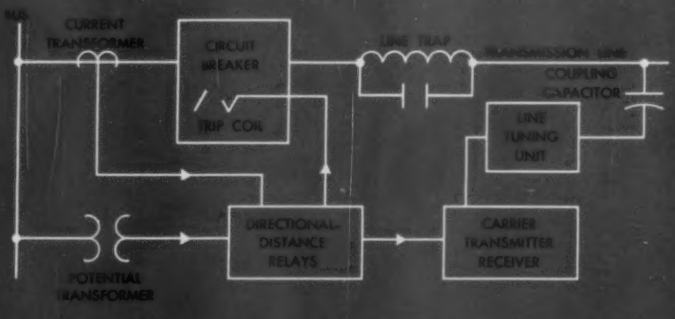


Fig. 1—The use of carrier in a basic directional-comparison system is shown. A similar station is located at the other end of the protected section. The relay receiver and directional-distance relays are so coordinated that a fault between carrier stations, indicated by a reverse flow of power at the end of the line, initiates breaker trip voltage.

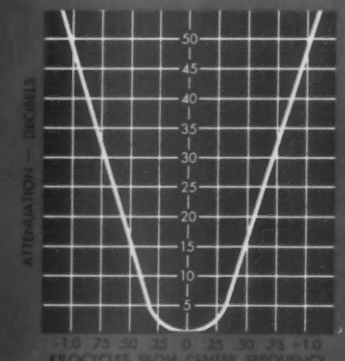


Fig. 2—Typical KR receiver selectivity curve.

without altering relay current. This is accomplished by operating in the saturation region. The sleet detector incorporates a potentiometer circuit that adjusts the transmitter output so the receiver will operate below saturation. Should a fault occur during a sleet test, the transmitter is returned to full output since the preference circuit for this feature is direct and instantaneous.

Voice Communication—The type KR relaying set is provided with a socket into which a voice adapter can be plugged. This adapter provides push-to-talk communication for installation and maintenance purposes. As with the other auxiliary functions, should a fault occur during conversation, the audio is instantaneously blocked and the relaying transmitter restored to full output.

general considerations

Relaying equipment must operate from a d-c supply so that, in the event of power failure, the set can continue to function. Since batteries at power stations may be 51, 129, or 258-volts, KR equipment is designed to operate from any of these supplies with minor modifications. For 258-volt operation, separately mounted dropping resistors are required.

Generally, transistors are more affected by temperature than vacuum tubes. However, stabilizing circuits and silicon-type transistors have decreased this disadvantage considerably. The KR relaying set is designed to operate between ambient temperatures of −20 degrees C to +50 degrees C with a minimum change in performance. Silicon-type transistors are used in the transmitter and receiver output stages.

Plate current can be cut off in a vacuum tube, but it is impossible to completely cut off transistor collector current. With zero emitter current, and at room temperature, the collector current is very small. However, with an increase in temperature, this current can become excessive, particularly when germanium-type transistors are used in a relay circuit. Therefore, the use of a silicon transistor in the relay output circuit of the receiver is highly desirable, since the silicon transistor is much more stable. This is also true for the transmitter output stage.

In vacuum-tube relay circuits where the tube is biased to cut off, cathode poisoning is frequently encountered, making tube operation erratic. Transistors have an advantage in this type of circuit, since no effect analogous to cathode poisoning has been encountered with transistors.

field tests

Experiments using transistors in power-line carrier equipment were started in 1952, and a year later a carrier transmitter and relaying receiver were designed. Field tests were first started on a 52-mile line section on the Potomac Edison system, between Ridgeley and Marlowe (Fig. 3). Total channel attenuation for this line was 41.5 db at a carrier frequency of 170 kc. A large portion of this attenuation could have been caused by a 12 000-kva transformer tapped in the middle of the line. Although the operation proved marginal, the sets were left in operation until February 1954 to check transistor performance. No failures resulted from these tests.

The sets were next installed on a 28-mile, 132-kv line section between Frederick and Marlowe with a carrier frequency of 120 kc. One transistor in the power amplifier failed after a total of 7000 hours operation. Since the transmitter had no output filter or protective equipment, line surges are believed to have caused the failure. A similar failure occurred about a month later. Installation of an output filter and protective equipment eliminated the failures.

In August 1954, new models were installed on the same channel. Improved power transistors were employed and a power output of over one watt was obtained. These sets operated continuously for 8500 hours without any change in performance or failure of any kind.

In June 1955, these sets replaced tube-type carrier on a channel between Marlowe and Reid at a carrier frequency of 70 kc. The transistorized sets operated continuously until November 1955, when the point-contact transistor in the oscillator circuit failed at the Reid substation. This oscillator was replaced with an oscillator circuit using junction transistors, and in January 1956, the oscillator at Marlowe was changed to use junction transistors. Since then, no failures have occurred.

The transistor, by its very nature, promised designers indefinitely long life, reduced set size, and minimum power requirements. Field tests have proven these promises true. ■

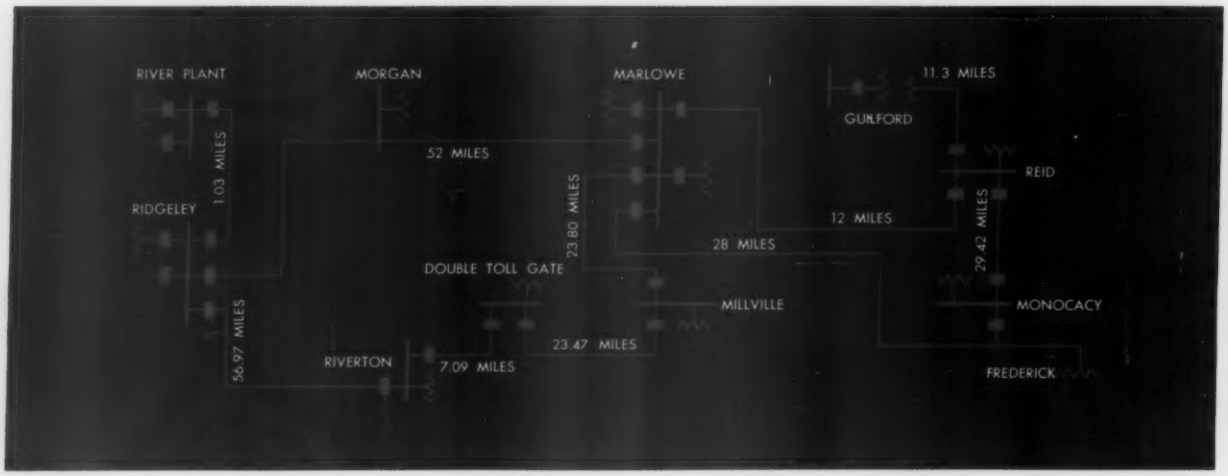


Fig. 3—Single-line diagram of The Potomac Edison Company 132-kv system.

Fig. 4—Simplified diagram of type KR relaying receiver.

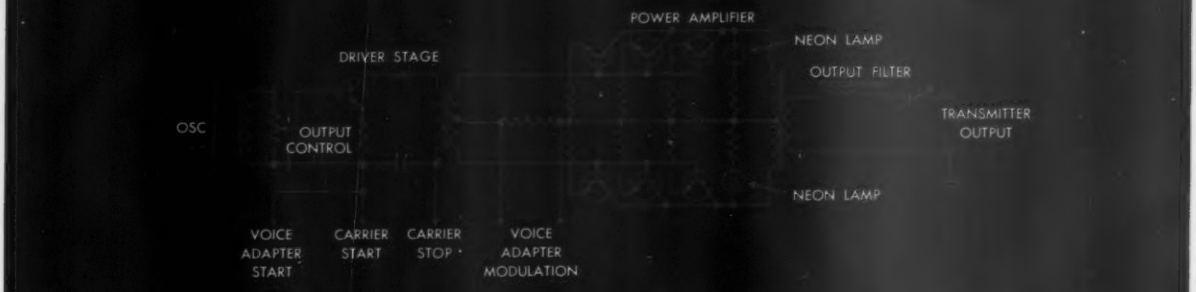


Fig. 5—Simplified diagram of type KR relaying transmitter.

Fig. 6—Simplified diagram of type KR voice adapter.

TRANSISTORIZED CARRIER OPERATION

Receiver—The transistorized receiver is of the superheterodyne type, which provides constant selectivity regardless of channel frequency. The major stages include an input filter, attenuator, oscillator, mixer, i-f filters, i-f amplifiers, detector, and output stage.

The oscillator is crystal controlled; the transistor circuitry is such that frequency is independent of voltage or temperature changes of the transistors. Hence, frequency stability is the stability of the crystal itself. The frequency of the oscillator is 20 kc above the incoming channel frequency. The receiver channel frequency is determined by the input r-f filter and the oscillator crystal. Both filter and crystal are plug-in components.

The i-f frequency is 20 kc and the overall selectivity is determined primarily by the i-f filter. The i-f amplifier consists of three transistors. The detector is a full-wave bridge rectifier. This rectifier, in conjunction with the i-f amplifier, provides the necessary power to drive the output transistor. The final output stage supplies approximately 18 milliamperes to a standard 1700-ohm distance relay coil and its associated 500-ohm alarm coil. The output can also be used to drive other relay coils for supervisory control and telemetering.

Transmitter—The transmitter consists of four main stages—an oscillator, driver, power amplifier, and output filter. The oscillator is basically the same as the receiver oscillator, except that the crystal frequency is at channel frequency. Input to the driver stage is controlled by a potentiometer, which also controls transmitter power output.

The power amplifier consists of six transistors operated class B in a push-pull parallel arrangement. Resistors in the emitter circuits provide d-c stabilization to prevent thermal runaway. If load is accidentally removed while the transmitter is in operation, current-limiting resistors connected in series with neon lamps are provided to prevent surges from damaging the output transistors. The output filter is tunable, and is provided to attenuate harmonics and other spurious outputs.

In relaying operation, the protective relays start and stop the transmitter. To start carrier transmission, contacts on the protective relays apply a positive voltage to the *carrier start* terminals, which unblocks the drive stage. To stop transmission, a blocking voltage is applied to the *carrier stop* terminals, blocking the driver stage and preventing carrier transmission.

Voice adapter—The voice adapter consists of an r-f amplifier, a power detector, and an audio amplifier. When receiving, the r-f input signal passes from the coaxial-cable connection on the type KR receiver through a section of the input filter to the receiver section of the voice adapter. This stage is transformer coupled to the power-detector stage, which drives the audio-output stage.

The audio-output stage serves two functions: it is the output stage for the receiver section, and also serves as the modulator for transmitting. Switching from *receive* to *transmit* is accomplished by pressing the pushbutton on the telephone handset, which energizes a relay. Contacts on the relay open the receiver circuit and close the circuit to the telephone microphone. The carrier transmitter must be unblocked before it is possible to transmit the modulated carrier signal. This is accomplished by applying carrier-start voltage to the transmitter through another set of contacts on the relay.

To prevent voice modulation when a relaying function occurs, the audio stage is blocked. The d-c voltage which unblocks the carrier transmitter at the carrier-start terminal is also applied to the voice adapter, and the differential is sufficient to block the audio stage. Carrier output is about 6 db less for communication than for relaying, so that proper blocking is provided. Thus, when a relaying function occurs while conversation is being carried on, speech is interrupted instantly.

For an application with supervisory equipment, the audio block is performed by use of supervisory preference contacts. These contacts open and remove the supply voltage to the voice adapter when a supervisory function occurs.

THE YANKEE PLANT... a new step in atomic progress

Progress in nuclear plants is steady. Each new plant adds to the technology available for the design of future plants. The Yankee pressurized-water plant is a case in point.

R. L. WITZKE,
Manager, Application Engineering

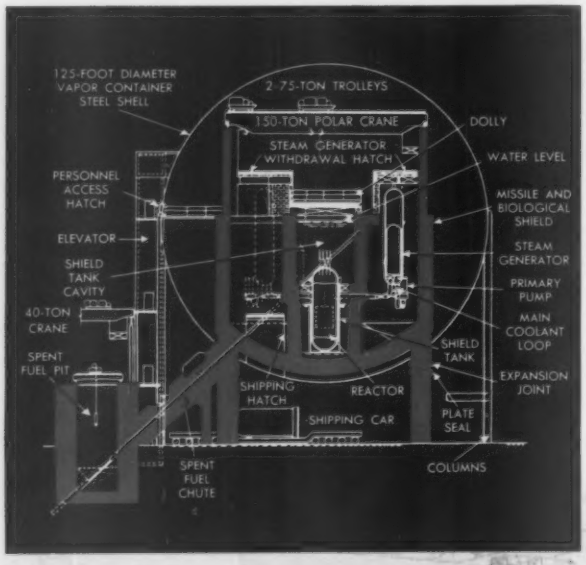
ALFRED E. VOYSEY,
Manager, Large Plants Engineering

Atomic Power Department
Westinghouse Electric Corporation
Pittsburgh, Pa.

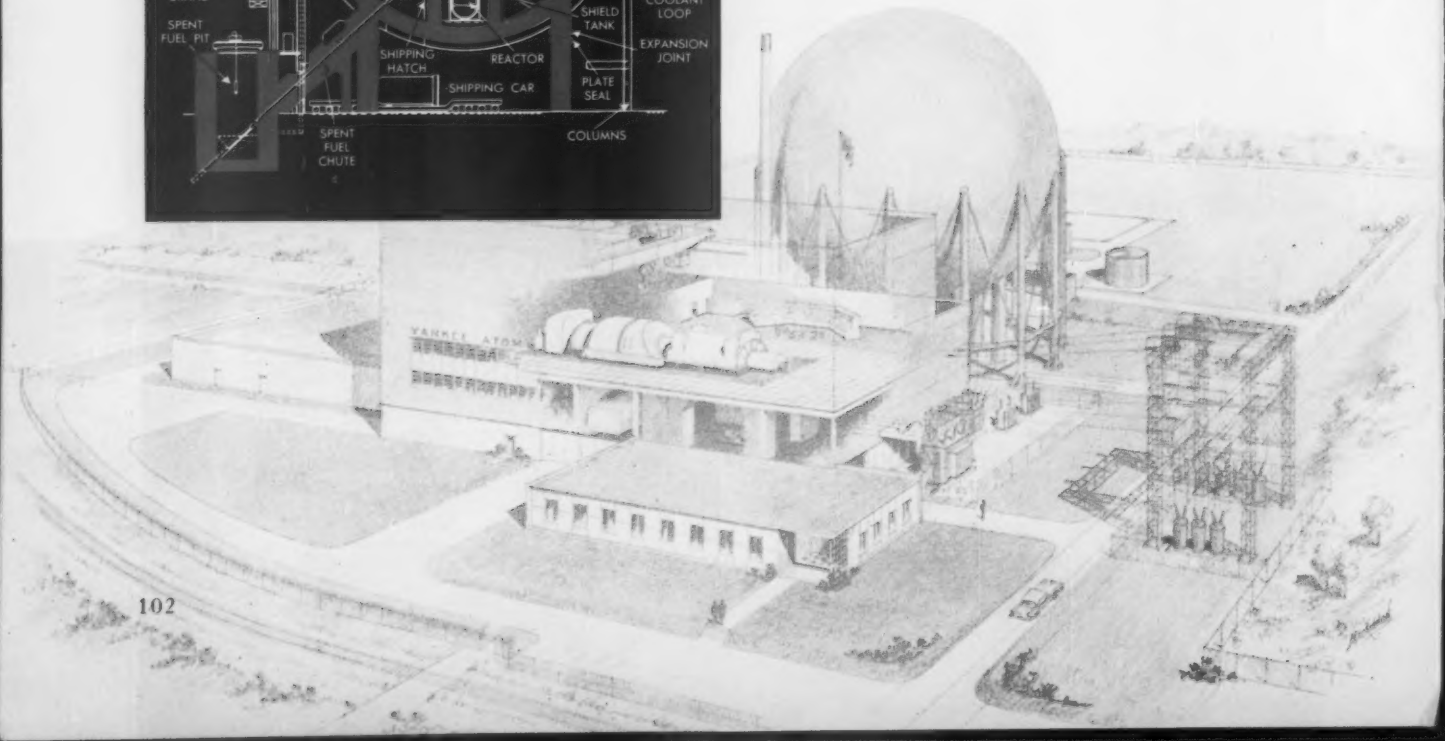
EDITOR'S NOTE: This article is based on information contained in two papers: "The Yankee Atomic Electric Company Nuclear Plant" by R. L. Witzke and A. R. Jones of Westinghouse; and "Yankee Progress" by Glenn A. Reed of Yankee Atomic Electric Company, W. E. Abbott and Alfred E. Voysey of Westinghouse, and Joseph V. A. Longcor and Walter C. Woodman of Stone & Webster. The latter paper was presented at the Nuclear Engineering and Science Conference in March 1958, and was sponsored by the ASME.

In the present state of nuclear technology, every new atomic plant can take significant advantage of the technology of previous plants. Not only is the art of materials advancing rapidly, but also the art of nuclear design itself. While it will be some time before nuclear design approaches an optimum, the changes made in successive plants are in themselves important progress. Such is the case with the pressurized-water plant now being built for Yankee Atomic Electric Company.

The Yankee atomic electric plant will be a pressurized-water plant using slightly enriched uranium. As mentioned in its general specifications, "The paramount design criterion is safety of the public and operating personnel. Otherwise, the design shall have the greatest simplicity, ruggedness, and economy consistent with reliability and efficiency within the special limitations imposed by a nuclear power plant. First cost is important and shall be kept to a minimum consistent with the cost of fuel, operating labor, and maintenance. Investment in all facilities not directly concerned with power generation shall be minimized."



Left—To remove fuel assemblies from the reactor vessel, the head fastenings are removed while the shield tank cavity is dry. The cavity is then filled with borated water. The reactor head and control-rod connectors are then removed and stored under water in the cavity. The fuel assembly is lifted out of the core, and placed in a shuttle, which transports it to the storage pit through the fuel chute. The shuttle and chute are designed to prevent free discharge of borated water from the shield tank cavity to the storage pit while a fuel assembly is being transported. Once in the storage pit, the fuel assembly is placed in a spent-fuel storage rack, and after the required decay period placed in a shipping container under water. Below—Architect's sketch of plant.



The Yankee plant is designed to demonstrate several things in achieving these goals. First is the feasibility of pelletized low-enrichment uranium-dioxide fuel, clad with stainless steel tubing. Second, the plant will demonstrate that construction cost can be reduced by using, as far as possible, standard equipment, designs, and construction methods used in the power production and chemical industries. Third, safety can be achieved by a sequential barrier arrangement between the fuel and the atmosphere. These barriers are: (1) the oxide fuel, in which the noncorrosive UO_2 fuel acts to contain the fission products within its matrix; (2) stainless-steel cladding in tubular form, with only two end welds per full-length tube; (3) a high integrity main coolant system; and (4) a containment vessel.

general description of the plant

The nuclear portion of the plant consists basically of the nuclear reactor and four loops, each having a vertical steam generator and main coolant pump. This primary plant has a capability of 482 000 thermal kilowatts and operates at a nominal 2000 psia, 514 degrees F average temperature.

Surrounding the entire nuclear steam-generating system is a spherical steel envelope. This contains all the pressurized parts of the main coolant system. This sphere is 125 feet in diameter and has a minimum plate thickness of $\frac{7}{8}$ inch.

The secondary turbine-generator plant has a nominal rating of 145 000 electrical kilowatts, a net output of 134 000 kw, and operates at 465 psia saturated steam pressure. The steam flows to an extraction turbine equipped with a moisture separator located between the high and low pressure elements. The steam cycle is designed with three stages of feedwater heating. The secondary system is located outside the primary plant container.

Many conventional steam power plants take advantage of the design margins of individual pieces of equipment and turbine generators to develop a maximum capability substantially in excess of nominal rating. While the excess capability of nuclear plants has not been established, there is no apparent reason why it should not exist. Therefore the conventional plant design has been arranged so that it may be possible to realize an ultimate capability of 160 000 gross electrical kw, without at the same time adding appreciably to the investment cost.

the nuclear reactor

Fuel for the first core of the nuclear reactor is uranium oxide (UO_2) clad with stainless steel. The uranium oxide is compressed into small cylindrical pellets and then sintered. These pellets have a diameter of 0.29 inch and are 0.6 inch long. A typical fuel rod will consist of a stainless-steel tube 94 inches long, containing about 150 of these pellets, and closed with stainless-steel plugs welded to the tubing.

One significant feature of these fuel rods is that they extend without interruption the full height of the core. This helps reduce local nuclear voids caused by interruption of the fuel column.

These fuel rods are assembled into a square array 7.5 inches square containing either 305 or 306 rods (two designs are used). Holes in the end plates of this assembly permit the coolant to flow between and parallel to the rods. Each fuel assembly can be inverted, i.e., changed end to end, which gives maximum flexibility in the interchange of assemblies during reloading. Rods are omitted, as necessary, in this lattice to provide slots for the cruciform-shaped control rods. The core contains a total of 76 of these fuel assemblies, and

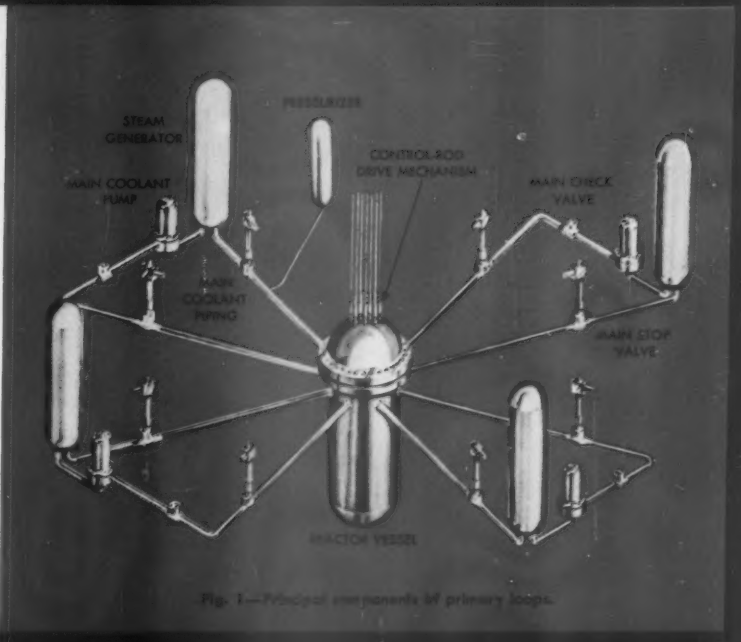
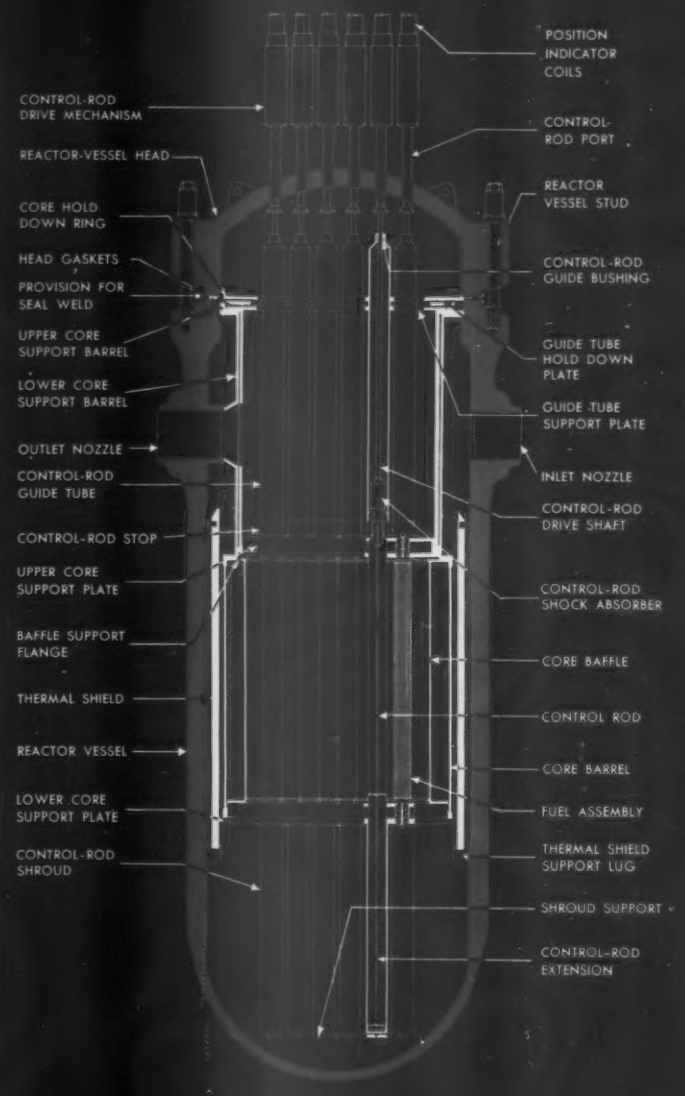


Fig. 1—Principal components of primary loops.

Fig. 2 — Cutaway of reactor vessel, showing reactor nomenclature.



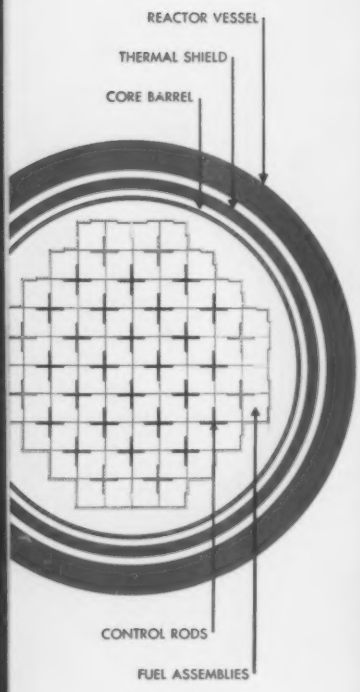


Fig. 3—Core cross section

Fig. 4—Fuel assembly

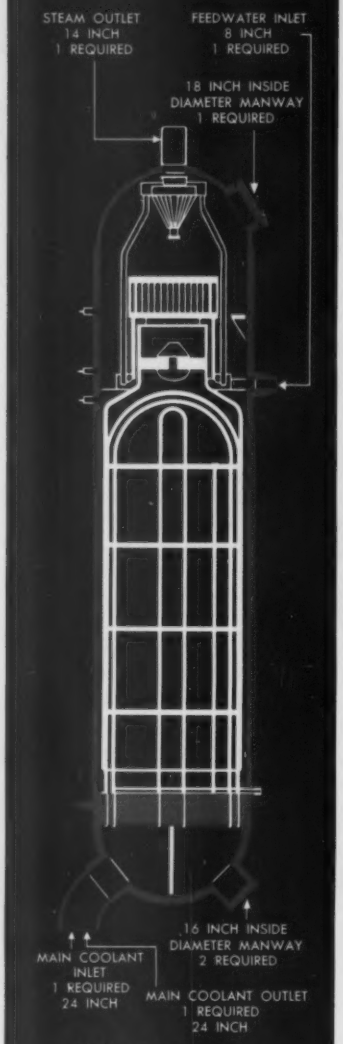


Fig. 5—Steam Generator

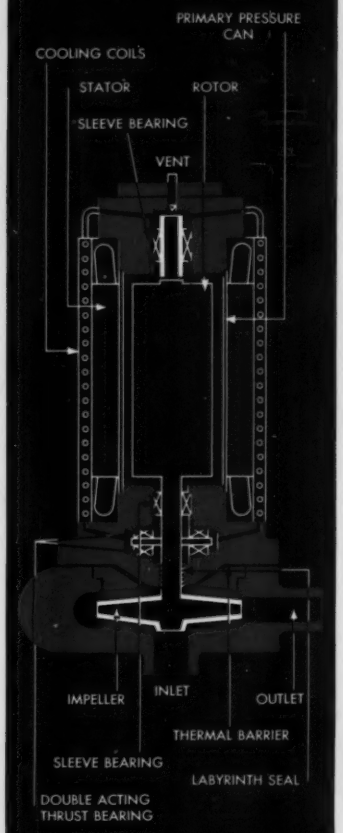


Fig. 6—Canned Motor Pump

has an active heat transfer area of about 15 400 square feet.

The core has an average diameter of 74.4 inches, an active height of 90 inches, and contains about 50 000 pounds of uranium oxide enriched to about 3.0 atom percent in U-235.

The core is designed for a life of 10 000 hours at a power level of 392 mw. This corresponds to an average fuel burn-up of 8200 mw days per metric ton of contained uranium.

Control Rods—After extensive research and development, a silver-indium-cadmium material was selected for control rods. These are 80 percent silver, 15 percent indium, and 5 percent cadmium, with extensions of Zircaloy-2 to act as guides. The rods are cruciform shaped and 24 are used.

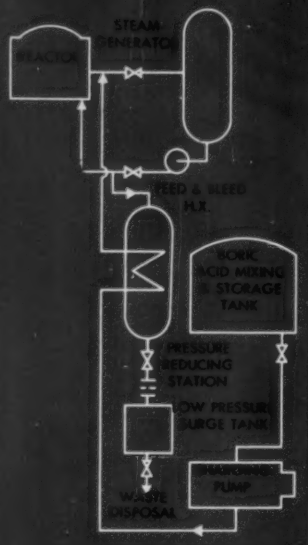
Although only 24 rods are used, the core has 32 slots for rods. The excess number can be used for "shimming" elements to adjust the initial reactivity of the core. Cruciform elements could be made up in either fuel or poison materials, or, if no reactivity effect is needed, of Zircaloy-2, a "neutral" material from a nuclear standpoint.

The control rods may be operated automatically or manually, but the exact method of programming is being studied. To get the control necessary to hold down the cold clean reactor, the control rods will be supplemented by chemical poisoning. A solution of borated water will be pumped into the reactor before it is to be cooled to room temperature.

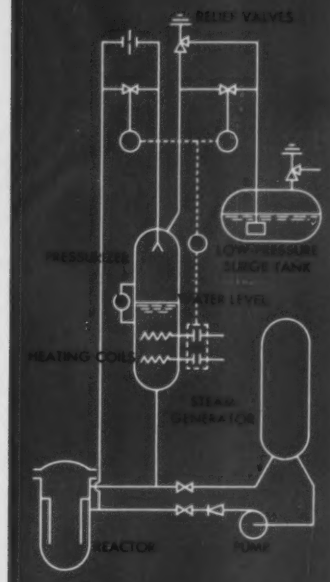
Pressure Vessel—The reactor core is located inside a vessel eight inches thick, 109 inches in inside diameter, and approximately 31 feet high including the head. The vessel is made of carbon steel clad on the inside with stainless steel. A full diameter head is used, which must be removed for refueling. Coolant enters the reactor vessel above the core level through 20-inch stainless-steel pipes, flows down through a reflector and thermal shield regions, and up through the core; coolant is conducted to the steam generators by four 20-inch outlet pipes, which also leave the reactor above the core level.

primary system

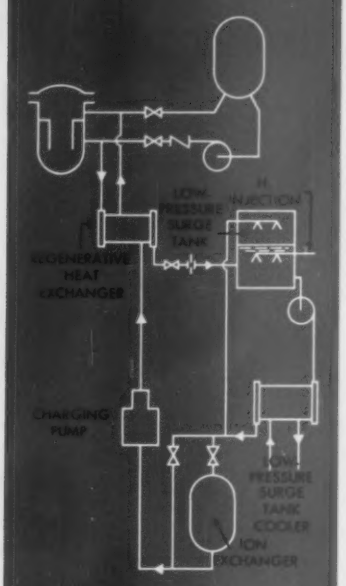
Each primary loop contains two stop valves, a check valve, a canned motor-pump, and a steam generator. The main coolant system is designed to transfer 1645 x 10^6 Btu per hour from the reactor core to the steam generators, which convert this heat into 1 840 000 pounds per hour of saturated steam. Main coolant is circulated at the rate of 37.8 x 10^6 pounds per hour, enters the reactor at 495 degrees F and leaves at 532 degrees. Normal operating pressure in the main coolant sys-



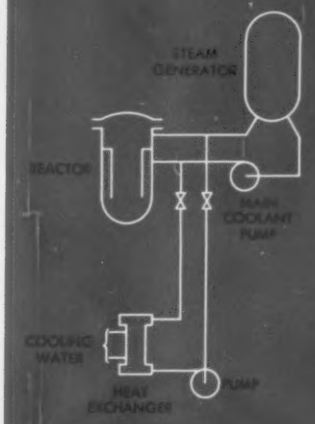
CHEMICAL SHUTDOWN SYSTEM—This is designed to inject a neutron-absorbing chemical into the main coolant system during shutdown, to complement the neutron-absorbing control rods. The system will function during a normal shutdown with the main coolant system at operating temperature and pressure, and not in those extreme cases where the time factor is critical, such as in the unlikely event of a large loss-of-coolant accident. The safety injection system, as described below, will be used in event of this large loss-of-coolant accident.



PRESSURE CONTROL AND RELIEF SYSTEM—This system is designed to maintain the primary coolant pressure at 2000 psia under steady-state conditions. Electric immersion heaters maintain a steam dome in the top of the pressurizer. Sudden loss of load would increase coolant temperature and volume and cause water to flow from the coolant system into the pressurizer vessel. Part of this flow passes through the spray nozzle and condenses some of the steam, which minimizes any increase in pressure. Decreases in coolant temperature and pressure cause water to flow from the pressurizer vessel into the system. Relief valves limit the system pressure to a maximum of 2500 psi.



PURIFICATION AND VOLUME CONTROL—This system bleeds and feeds main coolant for purification purposes, and maintains primary system coolant volume. The low-pressure surge tank acts as a storage vessel for water to be purified and cooled. Cooled water then passes through an ion exchanger, and the purs water is fed back through a regenerative heat exchanger to heat it to about the temperature of the primary coolant, then fed back into the system. If pressurizer water level falls, the automatic control starts the charging pumps, and varies their speed to hold the level.



SHUTDOWN COOLING SYSTEM—This system includes a pump and a heat exchanger, and serves to remove decay heat from the core when the main coolant system is depressurized. The initial stage of shutdown cooling is economically undertaken by using one of the steam generators as a cooler, until the temperature has been brought below 250 degrees F. The shutdown cooling system is placed in service only at pressures below 250 psig when the main coolant system is depressurized.

tem is 1850 to 2150 psia. The main coolant system is designed to permit a normal rate of load change of temperature of 10 percent a minute without undue surge or pressure and fluctuation. If necessary, full secondary plant load can be dropped essentially instantaneously.

auxiliary systems

The Yankee plant will have a number of auxiliary systems designed to maintain such things as water purity, pressure, and similar functions. Several of these auxiliary systems are diagrammed above.

One of the most interesting of these special systems is the safety injection system, which is designed to inject a large volume of boric-acid solution into the core in the unlikely event of a large loss-of-coolant accident.

Without such protection, the possibility exists that after the water left in the reactor boiled out, the decay heat generated could start to melt the core and its cladding. The possibility of this mass of melted core reforming a critical mass is unlikely, but must be considered; more important is the possibility of release of fission products, both gaseous and solid. To cool the core and maintain it in a sub-critical state, a large volume of borated water would be pumped into the main loops following any extraordinary accident. After the initial flooding, fresh solution would be slowly added for several days to continue to absorb decay heat given off by the core.

design considerations

As mentioned, the first core is designed to provide 392 000 kw of heat and 110 000 kw net electrical output at full power. Extensive studies are being made of means to increase core output from the nominal rating of the first core to the full plant rating figure of 482 000 kw. A review of hot channel factors following the critical experiment, provision in the plant for increasing the operating pressure to 2150 psia, and provision for multi-region loading are among the possibilities for increasing the first core output without increasing the physical size. However, if these possibilities fail, later cores can be increased in length to 8.5 feet, or rod size and pitch can be varied to produce the desired power.

The first core costs were figured on the basis of uniform enrichment, i.e., a single-region core, and a core life of 10 000 hours at 392 mw. This gives a fuel cost per net electric kilowatthour of approximately 4.0 mills, including chemical

processing of the clean fuel from UF_6 to UO_2, fabrication of the fuel assemblies, and reprocessing of the irradiated fuel.

However, current plans are to burn the core into a two-region core by replacing half the core after the equivalent of 5000 hours at full power. This will tend to equalize the power distribution throughout the core, i.e., flatten the power distribution in the reactor. At the end of 5000 hours the central 38 fuel assemblies will be removed, and the outer 38 assemblies moved into their places. New assemblies will replace the outer units. This "outside-in" loading scheme will permit the core to be run at a higher thermal output.

The neutron flux is greatest near the center when the reactor is initially loaded uniformly, therefore the highest rate of fuel burn-up occurs in the central area. The central units are then replaced with assemblies from the outer regions that are partially expended, or, in another light, are "less enriched" since they contain a smaller percent of fissionable material than new assemblies. In contrast, the new units inserted around the outside have the original enrichment. This has a tendency to balance out the power production so that the amount produced in the center assemblies is closer to that in the outer assemblies.

Basically, when the core has been rearranged there is more fissionable material in the outer assemblies, but fewer neutrons available for fission; conversely in the center there are more neutrons available, but fewer fissionable "targets." These two effects tend to cancel each other so that the power production in the core is more evenly distributed.

A major effort is being directed in the Yankee project toward reduction in the cost of fuel fabrication, through a relaxation in uranium-oxide specifications while obtaining a more uniformly controlled product, which will reduce pellet fabrication costs. Simplification of powder preparation is being investigated, as are various forming methods—for example, dry pressing and extrusion, which will permit the handling of fuel as long cylinders or rods. In general, large cost reduction will probably come only with more production, which depends on the number of plants using oxide fuels.

One present criteria in the design of the first core is that the fuel cladding be free standing. A thicker fuel cladding to achieve this would increase the overall fuel cost. Therefore considerable attention is being given to different methods of fabricating fuel rods with thinner cladding. One promising method now being studied involves stretch forming. Here the pellets are loaded into the tube and the tube stretched up to three percent. This method allows ample clearance for easy loading of the pellets into the tubes, and removes this clearance by stretching. This also improves the heat transfer from fuel material to coolant. While promising, this method has not as yet been thoroughly evaluated.

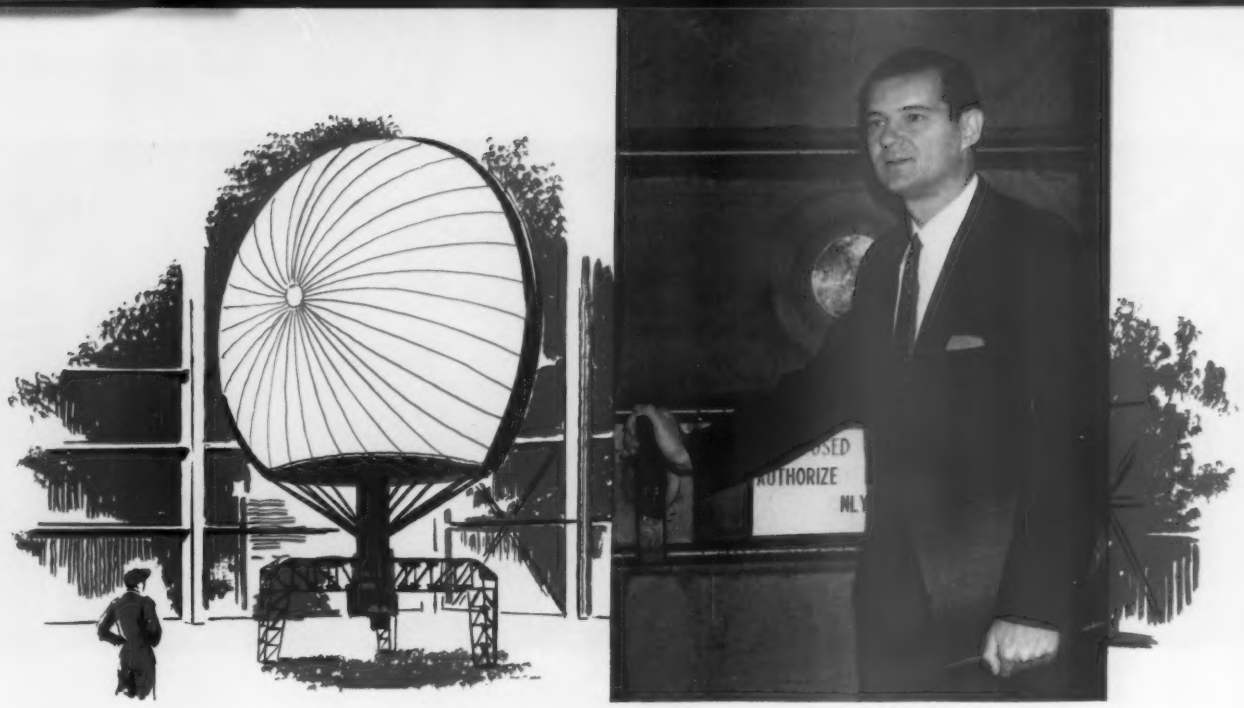
The vapor container for the Yankee primary system is designed to contain all vapors, gases, liquids, and solid materials released as a result of a loss-of-coolant accident. The size of this vapor container was determined by the space requirements for the internal structure and the polar crane for handling equipment. This established a vessel diameter of 125 feet and a gross volume of 1 020 000 cubic feet, or 840 000 cubic feet net. The spherical shape was selected because it uses a minimum of material for a given volume and internal pressure, permits the most accurate determination of secondary stress, and facilitates design of necessary penetrations. Although it is believed that no plausible missile could be released by the main coolant system, protection is provided by the inner concrete structure.

The initial design had the sphere supported on a conical skirt, which would have been the most economical available design in the use of material and would have kept secondary stress to a minimum. However, no fabricator could handle the course of beveled thick plate required at the junction of the sphere and skirt, so that the more conventional support from columns at the equator was finally employed.

While the Shippingport Station and the Yankee Station have different assigned functions and no direct comparisons can be made, a listing of some of the principal differences is interesting (see table). Full advantage was taken of the available information on the Shippingport Station; also, the Yankee plant could be simplified in design because the PWR plant incorporated many features to enable experimentation. ■

COMPARISONS OF SHIPPINGPORT AND YANKEE

	YANKEE	PWR
CORE DESIGN	Uniform loading	Seed and blanket
FUEL	Low enrichment UO_2 pellets	UO_2 pellets in blanket U_{233} plates in seed
FUEL CLADDING	Stainless steel	Zirconium
CONTROL RODS	Silver-indium-cadmium	Hafnium
COLD SHUTDOWN CONTROL	Control rods plus chemical	Control rods
VAPOR CONTAINMENT	Monocellular, above ground	Four connected cells, partially below ground
REMOTELY OPERATED VALVES	Electrically operated	Hydraulically operated
INSTRUMENTATION	Minimum consistent with power generation requirements	Consistent with both experimental and power generation requirements
FUEL STORAGE	Simplified pit	Canal consistent with experimental requirements
WASTE DISPOSAL	Simplified to suit power requirements	Capacity to suit experimental requirements of plant



engineering personality
COLEMAN MILLER

The Paraballoon antenna, an extremely lightweight mobile radar antenna of revolutionary design developed for the Air Force, was announced on these pages about a year and a half ago. Literally inflated like a balloon, this huge antenna is extremely lightweight and sectionalized, and can be assembled or dismantled in a matter of hours. Packed in cases weighing only 200 pounds each, the antenna can be air-dropped into tactical areas. The basic concept of this unusual development was the brainchild of *Coleman J. Miller,* Advisory Engineer at the Electronics Division. The value of Miller's contribution was recognized with a special $5000 award, which is the highest individual patent award the Company gives.

Patent awards are not unusual for Coleman Miller. He was presented with a $3000 award in 1951 for another outstanding invention, this one a dual-feed system for radar antennas. He has another $200 award the Company gives for particularly meritorious disclosures. Miller presently holds 11 patents, with 11 more patents pending. His patents apply to a variety of subjects—f-m transmitters, television circuitry, communications transmitters, and radar. Perhaps most significant is the fact that every patent disclosure that Miller has turned in has been accepted—certainly evidence of good sound engineering judgment on his part.

As an advisory engineer, Miller encounters a variety of technical design problems, usually in the radar field. His ability and willingness to help are much appreciated—and much used by his associates. They like to tell of one experience that happened about two years ago. A rather complicated radar antenna system was involved, and Miller was assisting the design group. The job was taking longer than the customer had anticipated, and on one occasion, the customer suddenly asked in effect, "Why don't you get an outside consultant to give you some help? Your neighboring division did this recently, and with excellent results."

And who was this outside consultant? The neighboring division had borrowed the consulting services of Coleman Miller.

Primarily, Miller depends upon an excellent basic understanding of science and physics. When someone comes to him with a problem, he immediately breaks it down into the simplest possible fundamental relationships, and builds from there. His first step is likely to be a simple sketch, with an indication of the basic mathematical relationships involved. He even accommodates to the point of writing and sketching with either his right or left hand—to give his listener an unobstructed view. He seldom uses a slide rule—he can work problems faster in his head.

Miller came to Westinghouse from Virginia Polytechnic Institute with a BSEE in 1941. Although he joined on the Graduate Student Course, he already had agreed upon a job in what was then called the Radio Division. A homemade crystal set during his junior high school days had started Miller's interest in things electronic, and he was determined to stay in this field. By 1942, he was busy designing highly secret "plumbing," radar antennas, and monitors. In 1945, in the beginning days of television he was assigned to the Stratovision project, where he helped investigate the feasibility of airborne television relay stations.

Miller was transferred to radar engineering in 1949, and worked on the design and development of shipboard and ground radar antennas. He was made supervisor in charge of the advanced development group for radar engineering in 1952. It was here that he came up with the Paraballoon concept previously mentioned. Two years later, he was made Advisory Engineer for radar engineering, his present position.

Away from work, Miller's interests have always centered around the water. He learned to swim at the age of five. At the moment, boating, water skiing, and fishing are his favorite sports. To be near the water, Miller converted a summer house on an inlet off the Chesapeake Bay into a year-round home. His boat, a 12-foot runabout that he built himself, is conveniently anchored only a few yards offshore.

Miller also admits to reading science fiction for relaxation. While this hasn't given him any specific help, he suggests that it does help in getting one to thinking unconventionally. Such unconventional thinking, but based on sound engineering principles, can be the prime ingredients for worthwhile inventions—like the Paraballoon antenna.

Left—Enclosures such as this one at Detroit Edison's Biltmore Substation are frequently used to reduce transformer noise.

Center—Inside view of the Biltmore Substation showing power transformer and barrier.

Right—Anechoic chamber is used to test production units and to study the causes of noise, enabling the construction of quieter transformers.

putting a blanket on transformer noise

THEODORE R. SPECHT, Transformer Division, Westinghouse Electric Corporation, Sharon, Pennsylvania

Transformer noise probably can never be entirely eliminated. But it can be reduced by using a low sound-level transformer, erecting acoustical barriers, or by placing the transformer in a large open lot. The choice between these methods, however, merits some careful consideration.

Transformer noise is fast becoming a prime factor in deciding the location and design of a transformer substation. Electrical loads are increasing, requiring the use of larger transformers, and for transformers of normal design the sound level usually increases with the rating. Also, they are being located closer to the load centers, making it extremely expensive to buy a large enough lot to dissipate the sound before it reaches the nearby residents. This leaves essentially two methods for reducing transformer noise to an acceptable level. A low sound-level transformer can be purchased at an increase in price, or a barrier can be erected around the substation. The cost and effectiveness of each method, of course, has to be evaluated in each specific case. But means of reducing transformer noise are worth considering in advance;

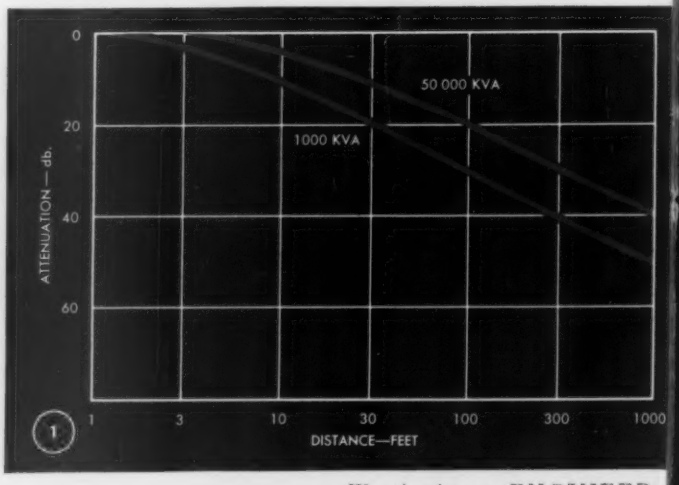
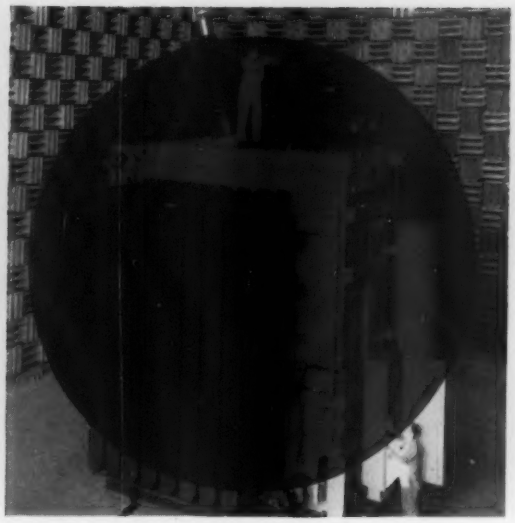


Fig. 1—The sound level naturally decreases with distance from a given transformer.

Fig. 2—Contours of equal sound pressure around a large power transformer. The sound level at any point about a transformer depends on: (1) the distance from the tank; (2) the height of the tank; and (3) the tank width as viewed from the point of measurement. *General Radio diagram*

Fig. 3—Typical ambient sound levels.



remedying a noisy condition after it exists may be more expensive, or even impossible.

source and transmission of transformer vibrations

Transformer noise is due to magnetostriction of the core material (the change in length of a piece of steel as the magnetic flux in the steel changes). These core vibrations are transmitted through the oil to the tank wall, which then also vibrates, radiating sound to the air. The tank, with any cabinets or other sizable objects on it (except the radiators), is considered as the source of the sound, Figs. 1 and 2. The usual types of cooling radiators are not effective sources of sound, nor do they attenuate the sound from the tank appreciably. For an object to be a good radiator of sound or an obstruction to the flow of sound, the shortest perimeter about the object must be more than one wave length. The wave length of sound at 120 cps is 9 feet, whereas the shortest perimeter of a radiator tube is usually 18 inches or less.

Transmission of vibrations through solid materials is not usually a problem with outdoor transformers. If the transformer sets on a concrete pad or foundation, the pad should not be directly connected to a building or the building will pick up the vibrations. The concrete pad should set directly on the ground. If it sets on bed rock, the vibrations can be transmitted through the rock to adjacent buildings on the same rock strata. Transformers set on the roof of a building, as in some hydroelectric generating stations, will certainly cause noise problems inside the building unless the transformers are set directly above massive pillars secured directly to a firm foundation. To eliminate the transmission of vibration to the supporting structure, the transformer can be set on springs or rubber pads. If the foundation is massive or rigid, and if the springs deflect $\frac{1}{16}$ inch or more due to the weight of the transformer, the foundation will not vibrate appreciably. If the foundation is light, or if the transformer is set on a relatively flexible surface, the springs must be even softer to prevent excessive vibration of the foundation.

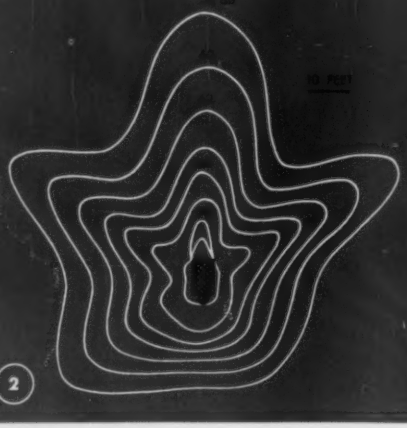
transformer audibility and acceptable sound levels

Transformer sound consists of a number of discrete frequencies. For 60-cps transformers, the important sound frequency is 120 cps. The harmonics of 120 cps are present, but their sound levels decrease with higher frequencies. The highest frequency of any importance is usually 1560 cps. Discrete frequencies are quite noticeable against the background of the usual ambient sounds. For this reason, transformer noise must be at least ten decibels less than the ambient sound to go unnoticed.

The sound from a transformer usually has to be reduced to about 40 db_{40} before it will be acceptable to the surrounding listeners, Fig. 3. For this reason, measurements of transformer sound are made on the A or 40 weighting network of the sound-level meter. The 40 weighting network is designed so all single frequencies that read 40 db on the meter sound equally loud to the ear. Actually, transformer sound consists of a number of frequencies, but one is usually louder than the others, so the meter will still give a fair approximation of the ear response.

designing transformers for sound level

Transformers in the range from 1000 to 10 000 kva usually give the most sound problems. These transformers are often located in residential areas and are too noisy to be inaudible at the boundary of a typical size substation lot. Transformers larger than 10 000 kva are usually located in more industrial



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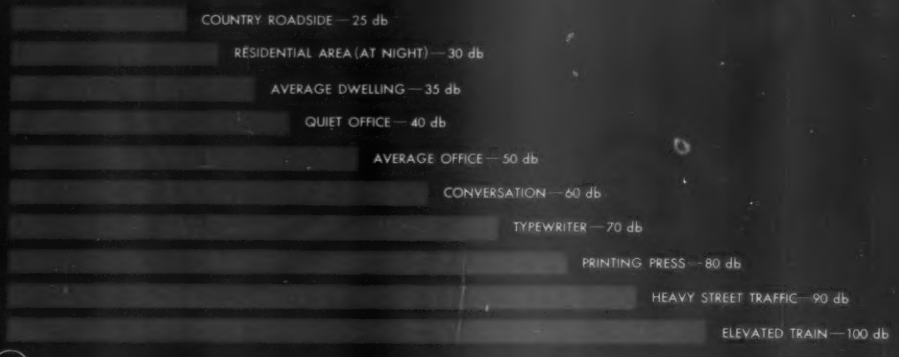
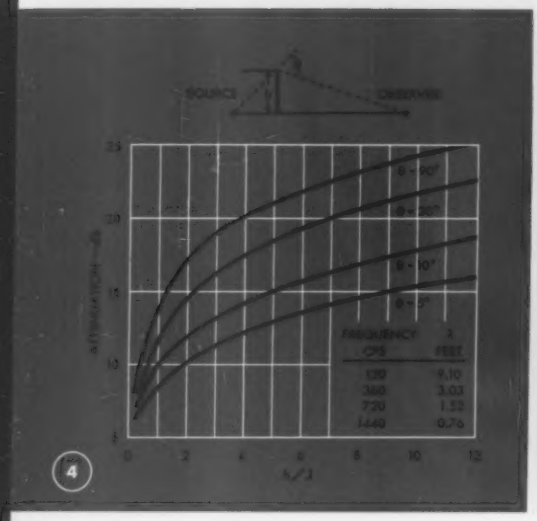
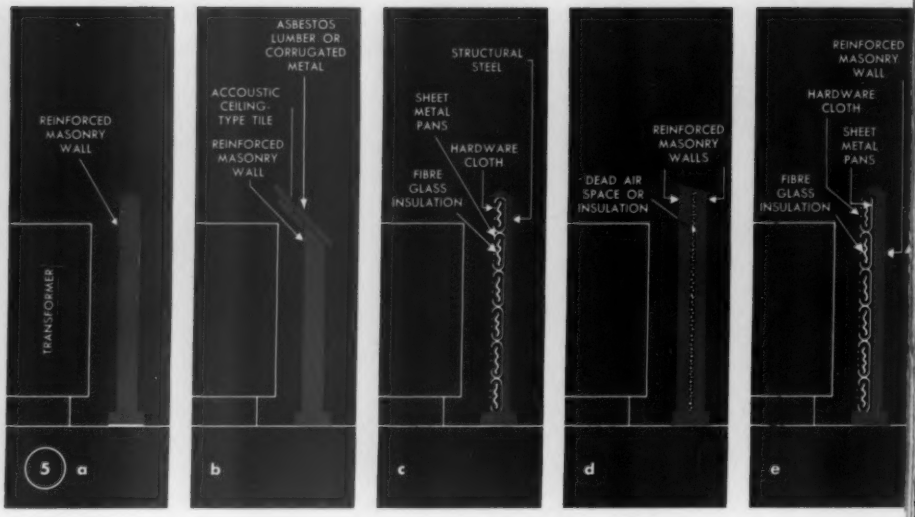

COUNTRY ROADSIDE — 25 db
RESIDENTIAL AREA (AT NIGHT) — 30 db
AVERAGE DWELLING — 35 db
QUIET OFFICE — 40 db
AVERAGE OFFICE — 50 db
CONVERSATION — 60 db
TYPEWRITER — 70 db
PRINTING PRESS — 80 db
HEAVY STREET TRAFFIC — 90 db
ELEVATED TRAIN — 100 db

3





areas where transformer noise is not such a critical factor.

If parts in a transformer are resonant at the fundamental frequency of vibration or any of the important harmonics, the amount of sound radiated is greatly increased. In effect, the resonant part provides a mechanism for transferring the low-amplitude, high-force vibrations of the core into a large-amplitude, low-force vibration that can effectively radiate sound into the air. The core itself is the most important resonant part, and its resonant frequency depends on the width of the iron laminations and the window opening (width and height). Combinations of these three variables that produce resonance at 120 cps or higher harmonics should be avoided. In oil-filled transformers, resonant panels are not a serious problem because the oil damps the vibrations, but they can occasionally cause a small increase in sound level.

If the transformer is secured to a concrete pad, resonance can occur in the enclosed air volume, increasing the sound level as much as 5 db. In a mechanically vibrating system, resonance can occur when a *mass* and a *spring* are coupled to each other. In the case of this cavity resonance, the air in the cavity acts like a spring. At the location of the ventilating openings, masses of air move back and forth essentially as solid masses. The spring of the air in the cavity depends on the cavity volume. The mass of the air in the ventilating openings is a function of the dimensions of the openings. Resonance is eliminated by properly proportioning the size of the ventilating holes with respect to the volume of air enclosed in the base.

The bottom of the transformer tank and the core and coils inside of the tank should have firm contact, especially in the core form of construction. To simplify assembly and removal of the core and coils from the tank, the bottom of the core is not bolted to the tank bottom, but is locked in by pins. Without firm contact between the bottom of the core and the tank bottom, the parts will rattle. To prevent this, the feet on the core touch the tank bottom in only three places. Locating structural members of the base directly under the mounting feet on the core prevents straining the bottom tank panel with the weight of the core and coils.

Hipersil, a cold-rolled grain-oriented steel, is used in Westinghouse transformers. Through the use of this material the permissible working induction of the core has been increased, resulting in smaller, lighter, and less costly units than those made of hot-rolled steel. Even at these higher inductions, the sound levels of transformers using Hipersil meet the sound levels set by the standards. The use of Hipersil has presented some problems because of its strain sensitivity. This property results in the generation of high-frequency vibrations that are especially irritating to the ear. A completely new method of handling core steel was inaugurated with the introduction of oriented steel. Particular care was taken to completely remove strains by proper annealing and to prevent other strains from being built into the core at assembly. This is very important in order to realize quiet transformers with Hipersil, which is inherently a low sound level material.

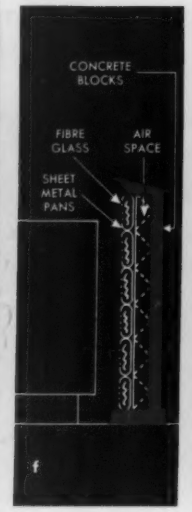
cooling fans for transformers

The NEMA standards permit an increase of 3 to 5 db with the addition of fans, increasing the transformer rating 33 percent. For smaller transformers, the fan noise predominates; the lowest sound level given by NEMA for a unit with fans is 70 db, 5 db higher than the transformer sound level without fans. Slow-speed fans can be used in greater number to obtain lower sound levels. This is advantageous where the transformer is designed with lower than normal sound level, and the fans must not add appreciably to the transformer noise. Sometimes there is an objectionable increase in noise level when the fans first start up. Turning the fans on in two stages helps in this case.

reduction of sound level through use of barriers

The most common method for controlling transformer noise is by the use of barriers. It can never be known with certainty if a noise problem will exist in a given neighborhood; sometimes the neighborhood can build up and surround the substation. However, with present manufacturing methods, a standard transformer can be 4 or 5 db below the NEMA level. For these reasons, standard transformers are often used, and barriers bought later if a noise problem results.

Four-sided brick enclosures usually reduce the sound level by 10 db_{40}. The wall should be spaced about four or five feet from the transformer, with the top of the wall four or five feet above the line of sight between the transformer cover and the point where the sound level is to be reduced. For the usual



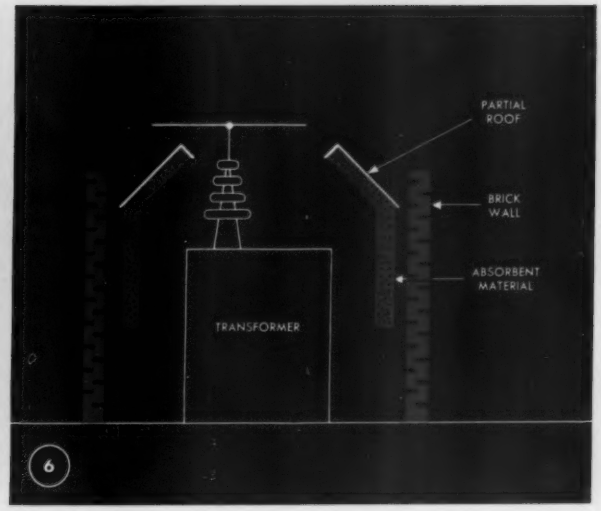


Fig. 4—Sound attenuation after erecting a barrier, where h is the height of the wall above the line of sight between sound source and observer, and λ is the wavelength of sound.

Fig. 5—Typical barriers used for attenuating transformer noise. *Source of diagram—AIEE*

Fig. 6—A high attenuation barrier and partial enclosure for a transformer.

size transformers (20 000 kva or less) the air circulation in the enclosure is sufficient, and the transformer does not have to be derated. For transformers larger than 20 000 kva, it may be necessary to derate the unit, use fans, admit air through the bottom of the wall through sound-absorbing air ducts, or space the walls more than five feet from the unit.

If the sound is to be controlled only in one direction, a three-sided or two-sided barrier can be used to reduce the sound off one side or off a corner, respectively. In these cases, where there are no multiple reflections as with a four-wall enclosure, the sound-level reduction will be 12 db, 40 weighting. A general curve for the attenuation due to two- and three-sided barriers is shown in Fig. 4. The height (h) is the height between the top of the wall and the center of the transformer. The wall should be at least as high as the transformer. If the attenuation is calculated on the basis of 120 cps sound, the attenuation of the db_{40} sound level will be about 2 or 3 db more than given by the curve, due to the presence of the higher frequency components, which are attenuated more than the 120 cps component. With a four-sided enclosure, lined with a good sound-absorbing material, the attenuation data for the two- or three-sided enclosures apply, as the lining prevents multiple reflections.

If the walls are made of cinder block or similar porous sound-absorbing blocks, the sound absorption is adequate. Sound transmission through these porous blocks is high, so to obtain attenuations higher than 10 db close to the walls according to Fig. 4, the blocks have to be given a coat of cement on the side away from the transformer, or a course of brick on the outside. The sound absorption of regular cement block can be improved by drilling two $\frac{3}{8}$ inch diameter holes on the side towards the transformer in a standard 8 by 8 by 16 inch block, one hole into each of the cavities in the block. This increases the absorption coefficient of the block to 0.8, by making it into a cavity resonator at 120 cps.

Prefabricated steel panel structures have a sound absorption lining on the side towards the transformer. Steel barriers are useful if changes in the station are expected. Also a brick wall might have one of these panels as a removable piece.

If more attenuation is desired than can be secured by a conventional barrier, a roof can be attached to the barrier (see Fig. 5b and Fig. 6). If the opening above the transformer is 10 percent of the plan area of the enclosure, the sound reduction due to the enclosure should be about 20 db. This assumes that the enclosure has good sound-absorption material on the inside. In Fig. 5b this requires sound absorption material on the inside walls; ducts to admit air at the base of the walls would also be desirable. Ducts have been made of the drilled concrete block referred to above. The ducts are each 6 inches wide by 36 inches high and 28 inches ($\frac{1}{4}$ wave length at 120 cps) long. The sound attenuation through these ducts is 20 decibels. With the proposed construction of Fig. 6, ventilating ducts should not be required. The partial roof is nonporous and is lined on the under side with sound absorbent material. The cool air will come down between the brick wall and sound-absorbent material and go up through the hole over the transformer.

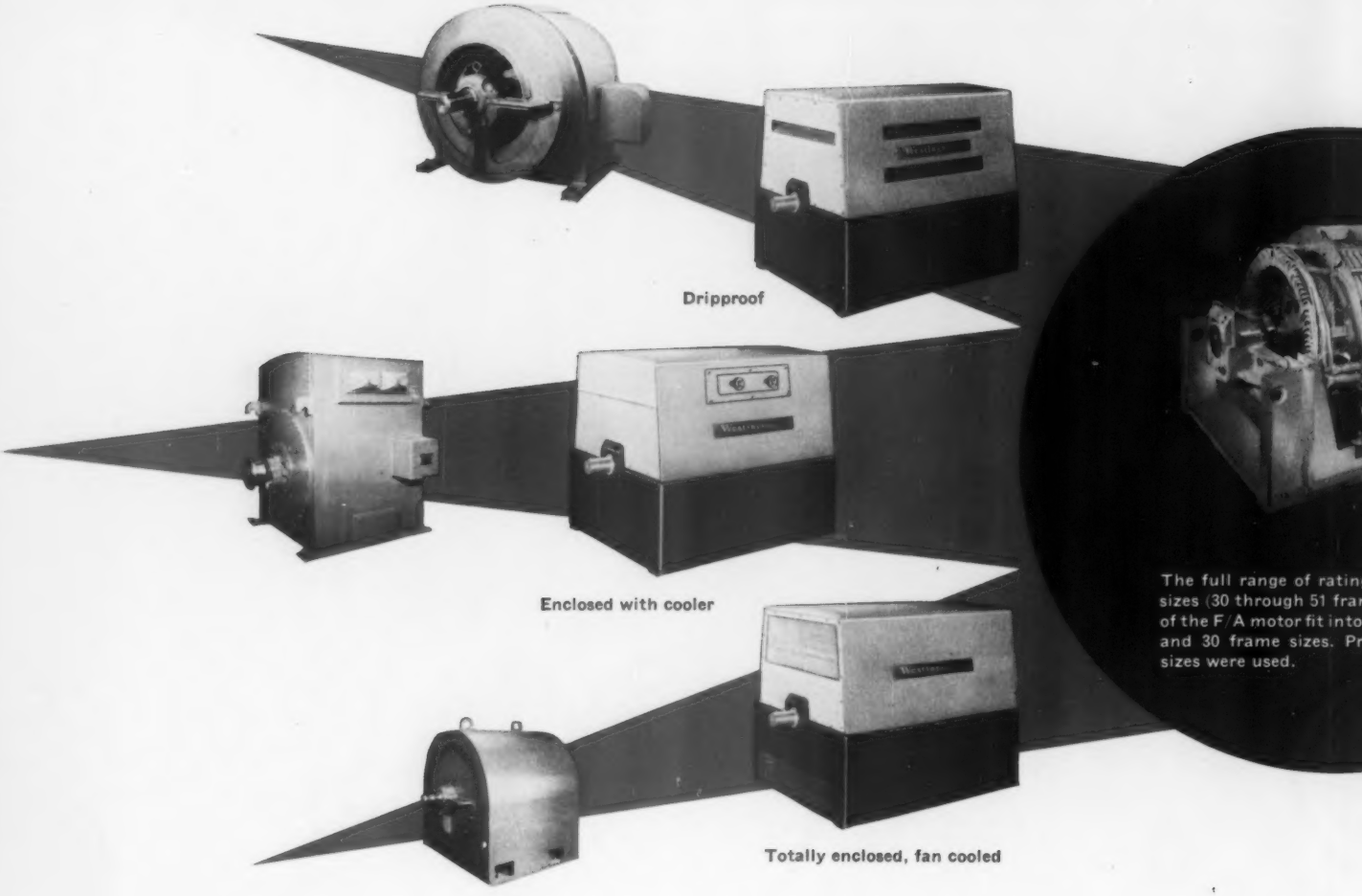
low sound-level transformers

The sound level of a standard 15 000-kva transformer, 69-kv class, self-cooled is about 72 decibels. The price of the transformer is in the order of $70 000. The price addition for this transformer for 12 db below normal sound level is 14 percent, or about $9800. A barrier giving an equal reduction in sound level costs about the same.

To achieve a lower than standard sound level, the transformer is designed with a reduced flux density. This requires more material and makes the transformer somewhat larger. The sound level of small power transformers is more difficult to reduce than that of large power transformers, as the NEMA standards require the small transformers to be quieter than they naturally would be relative to large transformers. This is reflected in the price additions. For a 60-db transformer, the price addition is 9 percent for a 6-db reduction, whereas for an 80-db transformer, it is 3 percent for a 6-db reduction.

Smaller distribution transformers can usually be placed far from a house, so they will be inaudible to the residents. It is normally impractical to make large power transformers inaudible in the usual distance available, about 200 feet, and 2-, 3-, or 4-sided walls may be necessary to reduce the noise to an acceptable level.

If sound is expected to be a problem in a given transformer installation, the relative cost of a wall and the increased price of a low sound-level transformer should be compared. ■


Dripproof
Enclosed with cooler
Totally enclosed, fan cooled
The full range of ratin
sizes (30 through 51 fra
of the F/A motor fit into
and 30 frame sizes. Pr
sizes were used.

Improved manufacturing techniques, l
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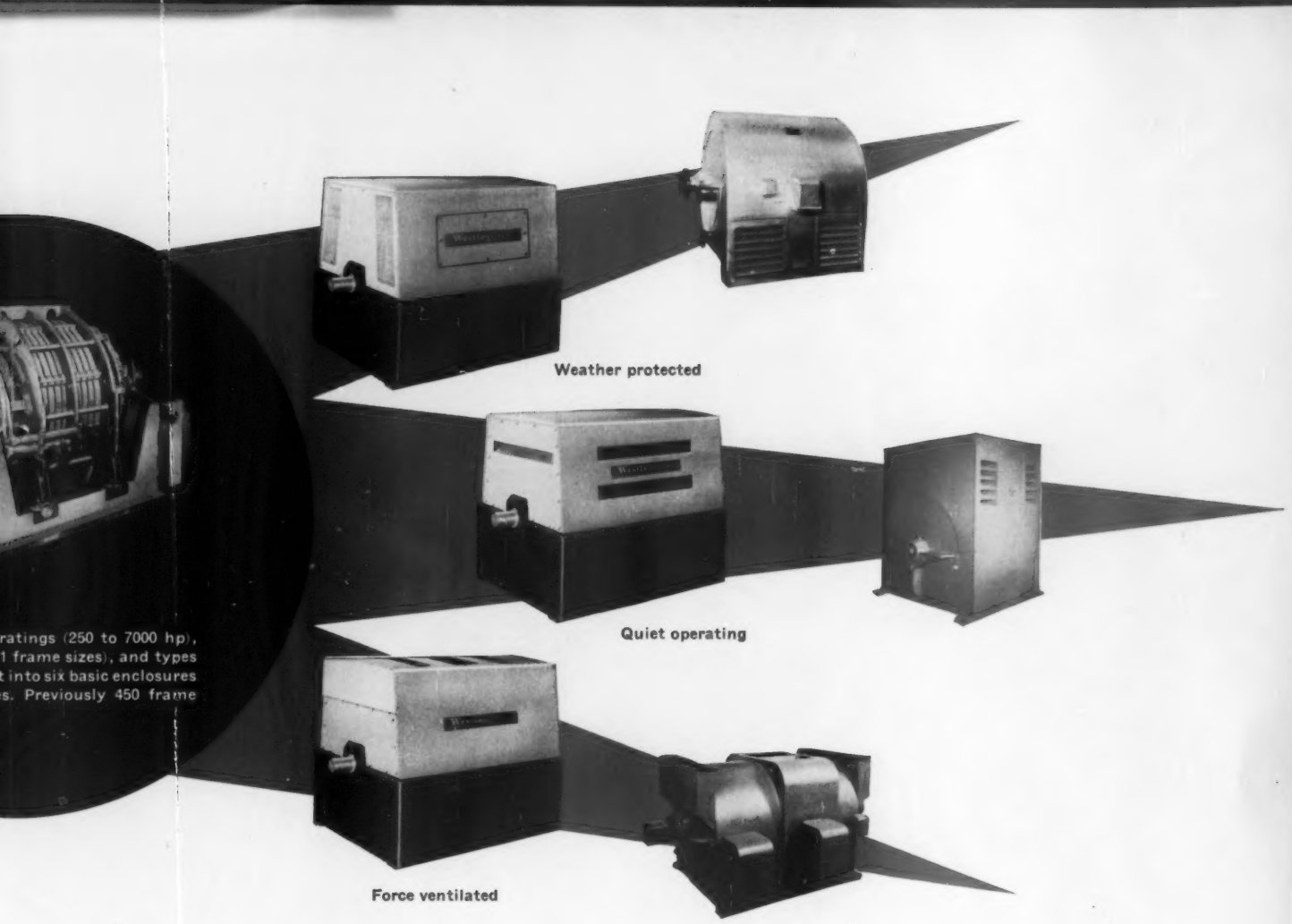
F/A MOTOR . . . fully accessible for inspection and maintenance

W. H. MORSE, Manager, A-C Motor and Generator Engineering Dept., Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

A new concept in large a-c motor design—the F/A (fully accessible) motor—makes the wound stator a component independent of the motor housing. Previously, the motor enclosure was welded or cast as part of the wound-stator assembly. In the F/A design, the enclosure is merely bolted to the base, so that the wound stator is fully accessible for inspection and maintenance; improved motor manufacturing techniques were also made possible.

All horizontal squirrel-cage, wound-rotor, and synchronous motors from 250 to 7000 hp for electric utility and industrial drive applications have been redesigned to use only five basic F/A motor enclosures. These basic enclosures are dripproof, weather-protected, force-ventilated, totally-enclosed, fan-cooled, and totally-enclosed-with-cooler. Six basic frame sizes are made for each of these enclosures, or a total of 30. This compares with 450 frame sizes formerly used. Each F/A-motor frame size replaces 15 of the previous line. For example, the two smallest frame sizes of the F/A motor replace 16 frame sizes of squirrel-cage motors, 16 frame sizes of the wound-rotor motors, and 8 frame sizes of the synchronous motors.

Because of the previous variety of motor types, ratings, speeds, enclosures, and applications in these large sizes, stand-



es, better accessibility, and standard-
de possible with this new motor design.

ardization was almost impossible. With the flexible new design, standardization becomes practical.

The reduced number of frame sizes offers a number of user advantages: identification of outline dimensions is possible without calculating a design so that the purchaser gets immediate service on outline drawings; quality is improved by repetitive precision manufacturing operations; and improved production schedules are possible because more parts can be stocked. Likewise, faster service can be given on replacement parts. Motor parts move in parallel to the assembly floor rather than in series as was required when the wound stator and enclosure were a single unit, which further helps reduce the manufacturing period and speed deliveries.

The F/A motor consists of four major structural components: rotor assembly, stator core assembly, base, and enclosure. Sub-components of these major components are the bearing brackets, side panels, air shields, end panels, and end covers. The motor is designed for ease in complete disassembly and reassembly. Components are designed for precise realignment, once they have been initially adjusted.

accessibility for inspection

The trend in recent years in large-motor design has been toward greater enclosure protection. However, because the stator has been integral with the housing, the result is a more complicated enclosure with reduced accessibility. Inspection was practically restricted to a look in at the motor ends. By making the enclosure removable, the whole stator can be inspected.

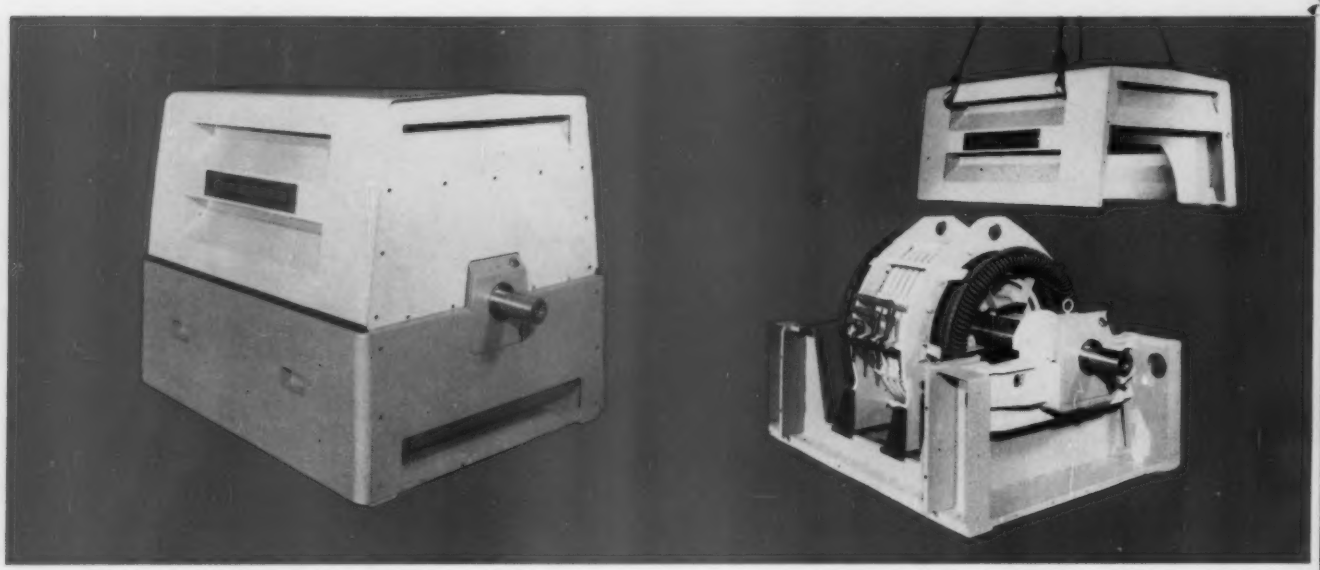
Like previous motors, the F/A design permits access for routine inspection from the ends. A side view of coils and core is added by taking off the side panels. Only four bolts need be removed to disassemble the enclosure, and expose the stator to full view. After the rotor is removed, the stator becomes completely clear of all other motor parts by unfastening four bolts from specially designed joints. These joints contain a built-in locating seat and do not require realignment. In fact, all motor parts can be removed from the base and reassembled without realignment. The base remains shimmed and doweled on the foundation during disassembly and reassembly of the motor.

This improved accessibility takes the guesswork out of inspection, and makes possible improved maintenance.

improved quality

Separation of the wound stator from other motor parts, besides being a major maintenance feature, also helps improve product quality. Stator winding has been a particularly critical manufacturing operation in previous motor designs because access was obstructed by the enclosure.

Another major manufacturing problem in large bracket-type a-c motors is boring the frame ends for the bracket fits concentric with the stator-punching core. Even with great machining care, uniform air gaps were difficult to obtain. Adjusting and doweling the brackets at assembly to obtain a uniform air gap has been the common solution. Therefore, proper motor operation is dependent upon tight bracket bolts, and assembly and disassembly are difficult. The F/A-motor design overcomes both problems. Plunge-bored brackets and base provide accurate rotor alignment. Air-gap uniformity is obtained by adjusting the stator during assembly; after adjustment, the stator is welded to the base through the four specially developed joints previously mentioned.



Typical of the new F/A motor line is this 700-hp drip-proof squirrel-cage induction motor.

With side panels, end panels, and enclosure removed, full accessibility is achieved.

The stator is accurately positioned with these locator fixtures to give correct air gap. Once welded in place, precise alignment is assured.

Each bearing bracket has two 2½-inch diameter plunge-bored spigots, which accurately fit the base and maintain rotor alignment.

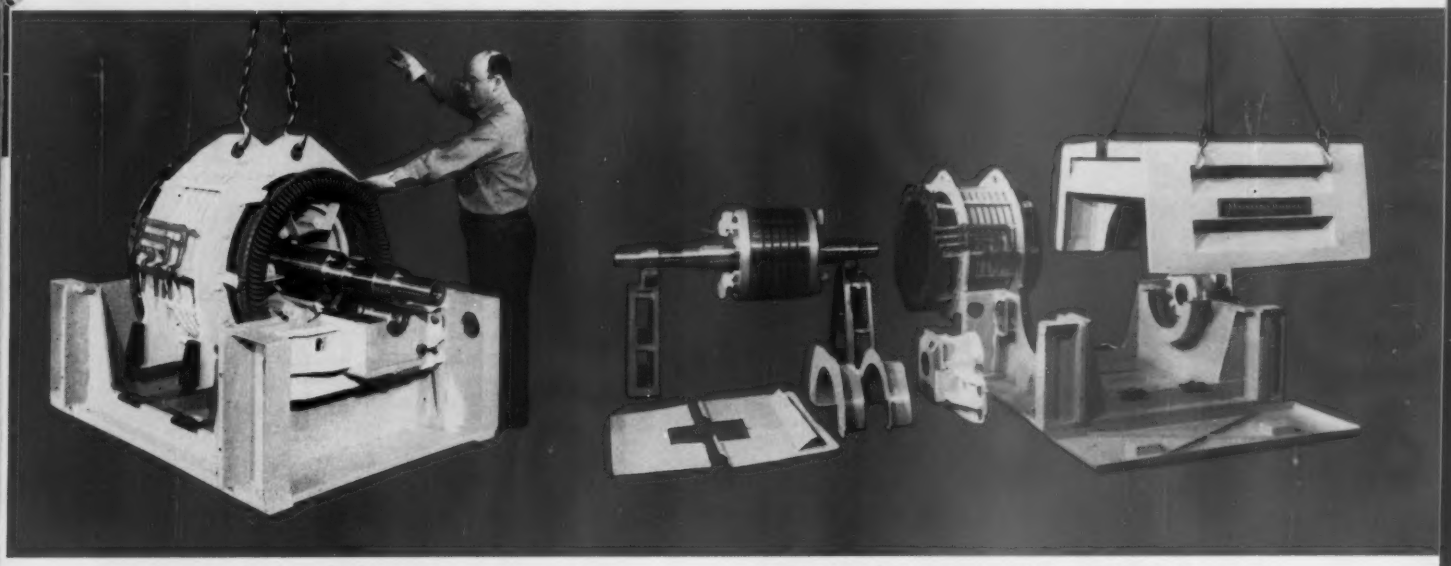
Bearings can be inspected after the removal of a few lightweight parts, without disturbing the bracket alignment.

installation

The conduit box has been eliminated. Removal of the side panels gives ample room inside the F/A motor for lead connections. Conduit and line leads enter through an opening in the base of the motor. If it is necessary for the leads to enter the motor from above, then a conventional box must be provided. A minimum of 14 inches head room is required to permit removal of the enclosure.

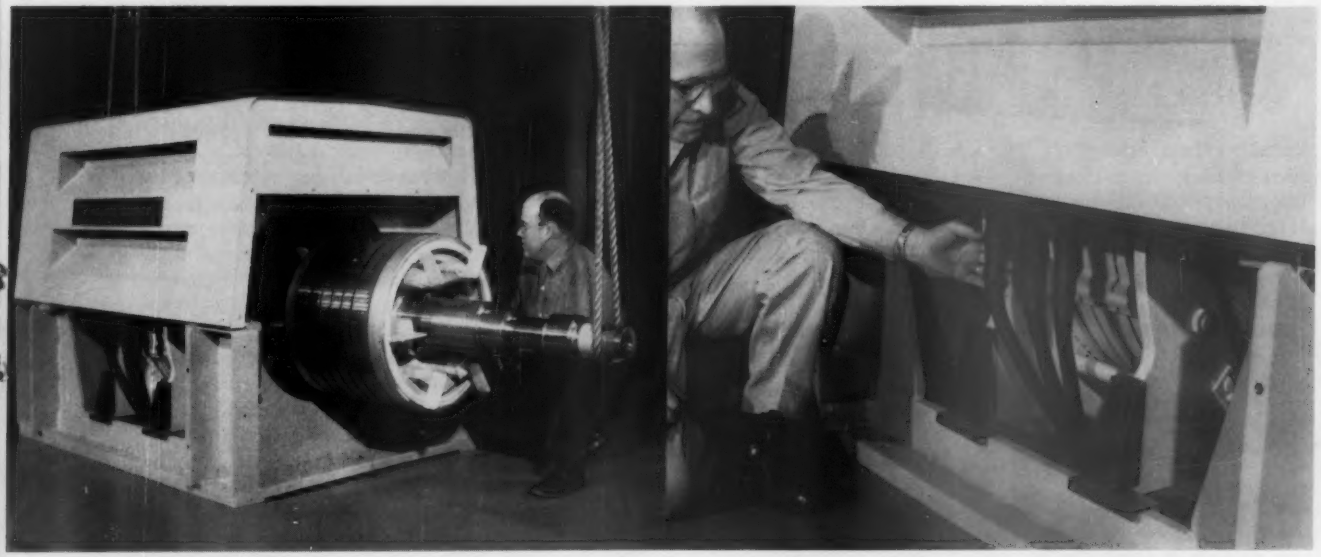
In recent years, the reduction of large a-c motor noise levels has been a major development project. Isolation of the wound stator from the enclosure inherently helps overcome transmission of magnetic vibration and noise. The F/A-motor design permits a further reduction of sound level after installation without redesigning. A variation in the basic F/A dripproof frame provides a sixth basic type of enclosure—the quiet-operating motor; noise mufflers and motor were developed simultaneously for maximum effectiveness.

Continuing research and development have resulted in improvements in design, methods, and materials. The improved F/A-motor design, combined with Thermalastic insulation, results in a motor of improved electrical and mechanical design that will assure long-term reliability and efficiency. ■



The stator can be lifted free of the base after removing only four bolts. Specially designed fixtures insure precise reassembly.

The F/A motor can be completely disassembled in only 30 minutes. Every part of the motor can be totally inspected and cleaned.



In addition to superior accessibility, all of the previously available disassembly features (like removing the rotor above) have been retained.

Side panel is removed to expose line connections. The large area in the F/A enclosure for connections eliminates the crowded, protruding conduit box.

semiconductors ... from crystals to devices

L. L. FRIEND,
Manager, Manufacturing
Semiconductor Department
Westinghouse Electric Corporation
Youngwood, Pennsylvania

Fig. 1—This furnace is used to "pull" single crystals of silicon or germanium for final processing into semiconductor devices. As purchased, semiconductor material is polycrystalline and unsuitable for use in devices. Similar furnaces use vacuum atmospheres—this one employs an inert argon atmosphere.

Fig. 2—A diamond cutting wheel is used to slice single-crystal silicon rod into wafers 0.010-inch thick.

Semiconductor devices are finding their way into an increasing number of industrial devices. Here's a look at how some of the semiconductor materials and devices are made.

The success of a semiconductor device depends to an unusual degree on painstaking care in the preparation of basic ingredients, and equal care in the manufacture of the devices themselves. For example, some materials must have one part impurity per several billion parts of semiconductor. In the fabrication of devices, the demands are not quite this stringent, but nonetheless extremely exacting. Consider, for example, some of the operations in the recently completed Westinghouse semiconductor plant.

Here the production of semiconductor devices is divided into functional areas, covering the operation from crystal pulling to completed devices. These include:

- Single-crystal pulling area
- Crystal slicing and preparation area
- Silicon-diode fusion area
- Low power silicon-diode line
- Medium power rectifier assembly line
- High power silicon-diode encapsulation line
- Rectifier bridge assembly area
- Audio transistor area
- Hyper-pure silicon production area

single-crystal pulling

One of the most exacting and difficult operations of semiconductor manufacture is the production of high-quality, high-yield, single-crystal material for subsequent device fabrication. Both germanium and silicon polycrystalline materials are "pulled" into single crystals in furnaces (Fig. 1) under either inert-gas or vacuum atmospheres.

Inert-gas furnaces predominate since most devices manufactured use n-type crystals, which must be pulled in an inert atmosphere such as argon.

The essential features of a typical gas-pulling unit are the crucible assembly, the pulling head assembly, power supply, and controls. The operating cycle is something like this: For silicon single-crystal pulling, a cylindrical flat-bottomed quartz crucible is used to hold an initial silicon charge of 90 grams. The crucible nests inside a cylindrical graphite crucible holder, which in turn is surrounded by a spirally-wound, water-cooled, high-frequency copper heating coil. This crucible holder and support assembly is designed to rotate counter-clockwise at 10 to 30 rpm.

A water-cooled crystal-pulling rod assembly is suspended

vertically above the rotating crucible. In operation, a two-inch-long "seed" of previously pulled single-crystal material is attached to one end of the pulling rod yoke, and this entire assembly can be rotated clockwise from 4 to 100 rpm, and moved vertically from 1.5 to 6 inches per hour. A charge of polycrystalline material is loaded in the quartz crucible and an n-type doping material is added. Then, the entire crucible and pulling-rod sections are assembled and isolated from the surrounding atmosphere by a quartz furnace tube about 3½ inches in diameter and 21 inches long.

To pull a single crystal, the material in the quartz crucible is brought to temperature: 1450 degrees C for silicon, 950 degrees C for germanium. Next, the pulling rod is lowered until the end of the seed contacts the melt and rotation of both seed and crucible is started. As soon as "points" form at the end of the seed, the seed is slowly withdrawn and the single crystal is pulled to completion, with rotation and withdrawal accomplished at a programmed rate. Temperature control is maintained during the pulling period within 0.1 degree C of the desired melt temperature.

For pulling of p-type single crystal for transistor devices, a vacuum atmosphere is used. The furnace construction is similar to that of the inert gas-pulling type, except that the charge is placed in a water-cooled metallic enclosure.

crystal slicing and preparation

Silicon and germanium single crystals arrive at this stage in the form of bar stock, and although the material is a single crystal, it is not uniform in its electrical properties along the length of the bar. Therefore, the bar is tested and marked along its circumference into desired resistance categories. The slices taken from each section are separated for use in particular devices to take proper advantage of the resistivity characteristics.

Once marked, the single-crystal bar is mounted on a steel rod and inserted into the chuck of the slicing machine. A diamond cutting wheel then slices the single crystal into wafers (Fig. 2) automatically, moving the bar stock up slightly after every slice.

The final single-crystal preparation consists of cutting circular silicon "dice" of exactly the right diameter desired. Common dice diameters range from ⅛ to ¾ inch. This dicing operation consists of ultrasonically grinding the circular shape from the original wafer.

Again, sample slices of the material from any given single crystal are tested for electrical characteristics to determine suitability for particular devices. The cut dice are then washed with solvents, dried, and checked for proper thickness.

The slicing operation for germanium single crystals is similar to that performed on silicon. However, since all germanium crystal produced is used for transistor devices, surface damage—due to cutting—must be removed from the slices by machine lapping (Fig. 3). This extremely sensitive operation automatically gauges and controls slice thickness, distribution of grit slurry, and cycle time. The lapped slices are then size-etched (Fig. 4) in acid to the required thickness, rinsed, dried, and inspected.

In contrast to the round silicon dice used for diodes, germanium transistor dice are square in shape. Silicon carbide grinding wheels cut the circular slices into dice for audio transistor use.

silicon-diode fusion

For practical use in semiconductor diodes the silicon dice must first be fused with counter-electrode and ohmic contacts.

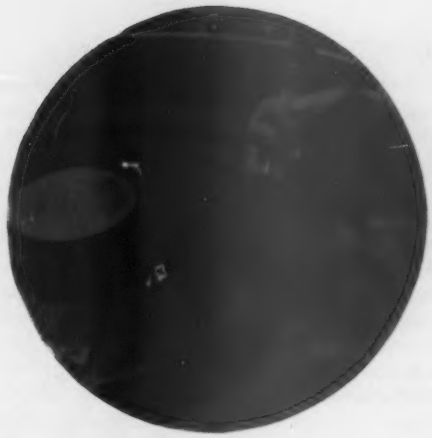


Fig. 3—This lapping machine is used to remove surface damage—due to the slicing operation——from germanium wafers. The operation automatically gauges thickness, distribution of grit slurry, and cycle time.

Fig. 4—After germanium slices are lapped, they are stacked in this polyethylene rack prior to an exposure to an acid-etching solution.

Fig. 5—Five-piece assemblies are loaded into holes in these graphite boats prior to inserting in a vacuum fusion furnace.

Fig. 6—The 18-inch-long graphite fusion boats are loaded into this vacuum fusion furnace. Small stainless steel weights are placed on top of each sandwich to give the right amount of compression during fusion.

This procedure involves making a "sandwich" of a base molybdenum wafer, an ohmic solder disc, the silicon disc, a counter-electrode solder disc, and another molybdenum wafer.

These five-piece assemblies are loaded in proper sequence into cylindrical holes drilled in graphite fusion boats (Fig. 5). Once loaded, small stainless-steel weights are placed on top of each sandwich to give the right amount of compression during fusion. Then the boats, 18 inches long and half-cylindrical in cross section, are loaded into a horizontal tube vacuum fusion furnace (Fig. 6). Each boat is fitted with a thermocouple to measure boat temperatures during fusion. The fusion of the parts is performed by first heating rapidly to the required peak temperature and then cooling rapidly.

The fused diodes are then unloaded from the graphite boats and tested for forward and reverse voltage characteristics. The sandwich is finally tinned prior to encapsulation.

low power (50 mil) silicon diodes

This line produces three types of rectifiers—the 307, 320, and the tv and radio rectifier, the 1N1169. The first two cover peak inverse voltage ratings from 50 to 1000 volts.

The encapsulation is a straight-line operation with all sequential welding and testing operations performed in an elongated dry box. The line is equipped with elastic-sleeved arm openings at each station through which the operator can work with ample freedom of movement. The Lucite front panels of this enclosure permit full view of each work station. Air humidity within the enclosure is maintained below a dew point of −30 degrees C.

Fused diodes are delivered to the first station of this line for testing. Diodes accepted for further processing in this line must have a satisfactory reverse leakage at 150 degrees C.

The trays are then moved to the internal spring weld station where a flexible conducting spring is welded to the top of the tantalum nail shank that serves as a base for each diode. From here the diodes are transferred to the next station, the external "top hat" projection-welding machine. The "top hat" portion of the case is cylindrical in shape and has a circular welding flange at the bottom and a compression glass seal at the top through which a thin hollow tube extends.

In this station, the primary encapsulation is completed by fitting the spring lead of the diode inside the "top hat" portion of the case and welding the flange to the molybdenum diode base. Several units of each lot completed here are removed to a leak detection station for leak testing.

Lots from this operation are then loaded in a vacuum where they are pumped down and back-filled with dry air. This is called a vacuum-flushing operation. "Flushed" diodes are then moved to a station where the thin hollow tube in each diode is crimped to hermetically seal each unit.

After other quality control tests to determine suitable electrical characteristics of each device, they are separated into various voltage classifications by a series of hot (150 degrees C) and cold (25 degrees C) tests. Classification is done on semi-automatic machines known as "pin ball" testers (Fig. 7). Their name is derived from lights that flash "on" in sequence during tests and indicate the voltage classification of each device.

medium-power rectifier assembly

This line produces four types of rectifiers as standard product with peak inverse voltage ratings from 50 to 600 volts maximum at peak inverse currents of 10 and 20 ma. However, many variations of the standard types are also processed for special order.

The encapsulation line is also a straight-line operation of elongated dry box construction similar to the 50-mil diode line. At the beginning of this line, the top header and spring assemblies are made.

The top header is a steel cylindrical member with a compression-type glass seal at one end, which supports a copper-plated alloy steel centerpost. A copper spring is soldered to the end of the centerpost.

Next, at the staking station, all the cell components are mechanically assembled. Here a screw-machined copper stud-type base, a pre-tinned silicon diode, a mica insulation washer, and the top header assembly are staked together by an air-operated staking tool and fixture. A solder ring is next lowered down around the top header until it rests snugly against the shoulder of the stud case (Fig. 8).

A number of these rectifier assemblies are loaded onto an aluminum soldering tray and placed on a hot plate and covered by a transparent Pyrex glass. During the soldering operation, a nitrogen-hydrogen mixture is introduced under

the Pyrex cover. A simple electrical test is then made to discard all "shorted" or "open" cells.

Subsequently, all units are leak tested, buffed, marked, nickel-plated, and inspected. Both a high-temperature (150 degrees C) classification and room-temperature classification are made (Fig. 9). A cell is always classified at the lower rating registered in each test.

high-power silicon-diode encapsulation

This line produces five types of rectifiers with peak inverse voltage ratings from 50 to 500 volts maximum at peak reverse currents of 40 and 50 ma maximum. These devices use the standard ½ and ⅝-inch diodes. Again, the enclosed dry-box production method is employed.

Again, at the beginning of the line, the top header and internal spring assemblies are made. The difference, however, is that for the high-power diodes, the compression spring is made of stainless steel.

The general scheme of operations is similar to those used in the medium-power diode assembly.

After all testing of these units has been completed, an external tinned-copper, flexible braided lead with spade terminal is swaged into the outer socket of the cell centerpost.

rectifier bridge assembly

A wide variety of bridge assemblies—mounted combinations of rectifier cells—is produced. For this reason, and because of the low volume associated with any particular type, little has been done to adopt mass assembly methods and techniques in this area. At present all bridges are hand assembled and hand soldered on work benches arranged for convenience of work flow. In general, assembly efficiency has been increased by the use of power-driven hand tools, and where volume has warranted, by relatively simple fixturing.

Typical units assembled here include single-phase battery charger bridges, three-phase welder bridges, and three-phase bridges used as replacements for motor-generator sets in some volume applications.

type 100 (audio) transistors

This production area is a product line in the final phase of manufacturing development. This means that each station, in manufacturing limited quantities of product, is being studied in detail for methods improvements. The present manufacturing operations are carried out in a totally enclosed "dry-room" area with every attempt made to maintain hyper-clean conditions.

Germanium dice are cleaned and dried before shipping to this area. Then the dice, tin-coated nickel-base tabs, indium emitter and collector pellets, and the collector and emitter lead wires are assembled at a fusion-boat loading station. Fusion of the complete assembly is then carried out in a special two-piece graphite fusion boat.

After the fused assemblies pass an electrical test, they are welded to a base tab and header. As can be imagined, these welding operations are extremely precise and must be performed by tweezer-weld machines with special holding fixtures and welding electrodes. After more testing and cleaning processes, the units are now ready for final capping, painting, and shipment.

hyper-pure silicon material production

Until recently, available silicon has left something to be desired in the way of quality.

Manufacturers of devices have found that this silicon, while pure indeed, is not pure enough. Using the best available material, fused large-power diodes can be made with ratings to 500-volt peak inverse voltage. Purity of silicon had to be improved so that the peak reverse voltage characteristic would range to 1000 volts.

The Siemens process as recently developed by the Siemens Schuckertwerke and Siemens Halske in Germany, in conjunction with work done by Westinghouse, has produced silicon material to satisfy the above requirements. Through an agreement with Siemens, Westinghouse has licensed this process in the United States.

A pilot facility (Fig. 10) has been installed for working out quality and yield improvement problems of this process.

Because of the exacting standards necessary to achieve desired characteristics from semiconductor devices, production facilities are unique. As the industry grows, many changes will undoubtedly take place in the facilities as a result of new technology. Full provision is made for such flexibility in this new plant. ■

Fig. 7—Low-power tv diodes are separated into various voltage classifications in this "pin ball" tester. As each diode is tested in turn, lights in the row flash on in sequence. The last lamp to remain lighted indicates the voltage classification. The operator merely drops the diode under test in the bin below the lamp.

Fig. 8—In the medium power rectifier assembly line, a solder ring is lowered down around the top header to fit snugly against the stud case. The soldering operation will be conducted on a hot plate in a nitrogen-hydrogen atmosphere.

Fig. 9—This test console is used to make high-temperature (150 degrees C) and room-temperature voltage classification of high-power diodes.

Fig. 10—This is part of the pilot facility at the Westinghouse semiconductor department plant to produce hyper-pure silicon by the Siemens process. Through an agreement with Siemens, Westinghouse has licensed this process in the United States.

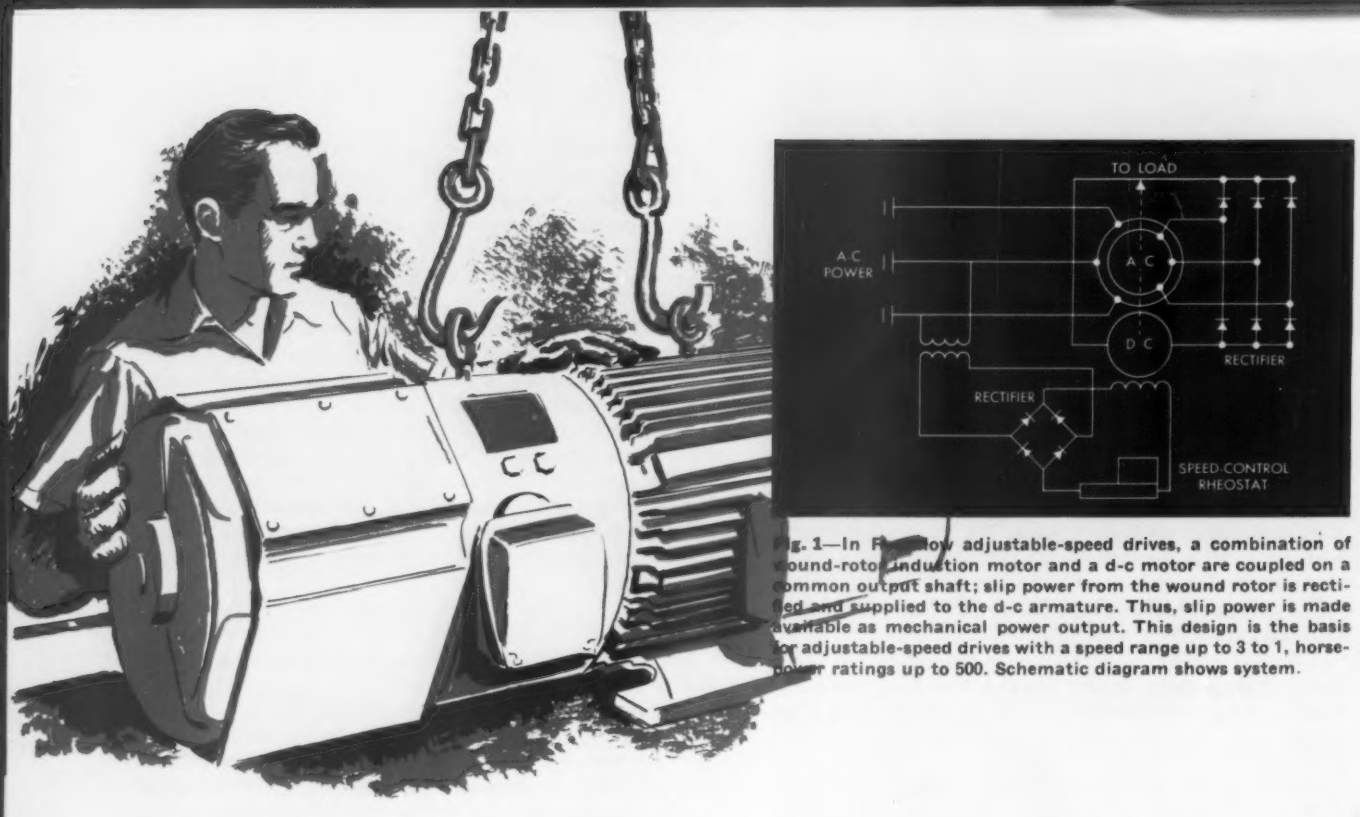


Fig. 1—In Rectiflow adjustable-speed drives, a combination of wound-rotor induction motor and a d-c motor are coupled on a common output shaft; slip power from the wound rotor is rectified and supplied to the d-c armature. Thus, slip power is made available as mechanical power output. This design is the basis for adjustable-speed drives with a speed range up to 3 to 1, horsepower ratings up to 500. Schematic diagram shows system.

rectiflow drives

W. R. HARDING, Assistant Manager, Motor Engineering Department, Westinghouse Electric Corporation, Buffalo, New York

In their newest application, semiconductor rectifiers make possible a new approach to a-c adjustable-speed drives, one that provides a number of unusual characteristics.

A combination of an induction motor, a d-c motor, and semiconductor rectifiers forms the basis for a new concept in a-c adjustable-speed drives. The result is a packaged drive that provides continuously variable speed control over speed ranges of 1½ to 1, 2 to 1, or 3 to 1, with a maximum speed of 1690 rpm.

Basically this package—called the Rectiflow drive—consists of a wound-rotor induction motor and a d-c motor built on a common output shaft (Fig. 1). Associated with these motors is a set of semiconductor rectifiers that convert the slip power of the wound rotor to d-c, which is supplied to the armature of the d-c motor. An additional group of rectifiers is supplied to convert alternating current from the incoming power line to direct current for the d-c motor shunt field. A rheostat in the d-c field makes it possible to control speed simply by adjusting the field strength of the d-c motor.

Several features of this system are immediately apparent. First of all, the d-c motor converts the slip power to mechanical power output. Conventionally this slip power is not available. The separately excited field circuit of the d-c motor permits speed control. The speed range is determined by the base speed of the d-c motor and the relationship of its rated voltage to the induction-motor rotor voltage.

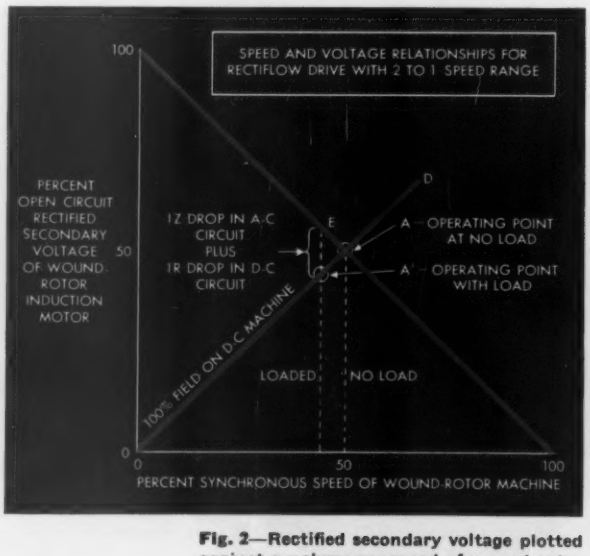

SPEED AND VOLTAGE RELATIONSHIPS FOR RECTIFLOW DRIVE WITH 2 TO 1 SPEED RANGE
100
PERCENT OPEN CIRCUIT RECTIFIED SECONDARY VOLTAGE OF WOUND-ROTOR INDUCTION MOTOR
50
0
IZ DROP IN A-C CIRCUIT PLUS IR DROP IN D-C CIRCUIT
D
E
A — OPERATING POINT AT NO LOAD
A' — OPERATING POINT WITH LOAD
100% FIELD ON D-C MACHINE
LOADED
NO LOAD
0
50
100
PERCENT SYNCHRONOUS SPEED OF WOUND-ROTOR MACHINE

Fig. 2—Rectified secondary voltage plotted against synchronous speed of wound-rotor motor for a 2-to-1 Rectiflow drive.

Interesting variations can be made on the basic circuit. For example, regulators can be added in the d-c circuit to give variations in performance similar to that possible for a typical d-c motor. This, in turn, varies the overall performance of the drive. Also, the basic drive circuit permits the addition of such devices as reactors, autotransformers, and resistors to secure many useful results.

For the a-c motor part of the basic drive, the operation resembles a conventional wound-rotor motor. From the d-c machine, on the other hand, are obtained the characteristics that are unique. A counter-emf that bucks the rectified a-c rotor circuit voltage is generated by the d-c motor. The difference between these voltages is such that the rectified rotor voltage is just sufficient to circulate load current through the a-c rotor, the rectifier, and the d-c armature. If the d-c motor field is weakened during operation, the counter-emf decreases, allowing more current to flow. This produces more torque in both a-c and d-c machines and the drive accelerates to a higher speed; as the speed increases, the rotor slip voltage decreases and the counter-emf increases. Accordingly, acceleration ceases when these voltages differ by the amount required to circulate running load current at the new speed.

The basic Rectiflow drive is controlled by a field rheostat that determines excitation of the d-c motor (Fig. 2). The rectified a-c secondary voltage and the d-c armature voltages are shown as functions of drive speed. If the d-c field is open and the Linestarter is closed, the Rectiflow drive comes up to full speed. The performance under these conditions is exactly the same as for a wound-rotor induction motor with a small amount of external secondary resistance. When the d-c motor field is strengthened to 100 percent, the d-c voltage rises to the value marked *D* on the diagram. This voltage is higher than the secondary a-c voltage and no current will flow from the a-c wound rotor through the rectifier and through the d-c machine. Thus drive speed will decrease until the point *E* is reached, where the a-c secondary voltage is higher than the d-c counter-emf and current flows. The current produces torque in both the a-c rotor and d-c armature. As additional load is applied, the speed drops slightly, the a-c voltage increases and the d-c counter-emf decreases to an extent permitting more current to flow until the required torque is obtained.

The rectifiers in the basic package (Fig. 3) are an important aspect of the drive and received special consideration in the development of this design. Rectiflow drives up to 60 horsepower can be started across the line and will draw five to six times full-load current from the power source. Normal design for the a-c stator, d-c armature, a-c and d-c brushes will permit this inrush of starting current for approximately 10 seconds. A sufficient number of rectifier units are used in parallel to secure the same margin on inrush current.

The back-voltage requirements of the rectifier are determined by the rated voltage of the d-c motor and the peak d-c voltage incurred in operation. The voltage across the rectifier is determined by the secondary voltage of the wound rotor and the counter-emf of the d-c motor, as shown in Fig. 1. The peak voltage is the d-c voltage that occurs when the Rectiflow drive is operating at full speed and the shunt field is applied at full strength. The d-c peak voltage is twice the rated voltage on a Rectiflow drive of 2-to-1 speed range and three times rated voltage for a drive with 3-to-1 speed range.

For a drive with 2-to-1 speed range the number of units required in series is the same for all steady state and peaks. For a speed range of 1½ to 1, the switching surges determine the number of units required in series. On a 3-to-1 speed range the voltage peak on strengthening the field determines the number of cells required in series. For this speed range, in some cases an over-voltage relay is used to reduce the number of units required in series.

One method of obtaining reduced torque and reduced current at starting is the use of a double-delta primary on the wound-rotor motor. Two standard Linestarters are used on the double-delta winding, as shown in Fig. 4. This scheme will reduce the a-c starting current to 50 percent and the torque to 25 percent of normal starting torque. Note that the complete winding is in the circuit and that each starter takes only half of total running current. Other reduced-voltage schemes are also practical.

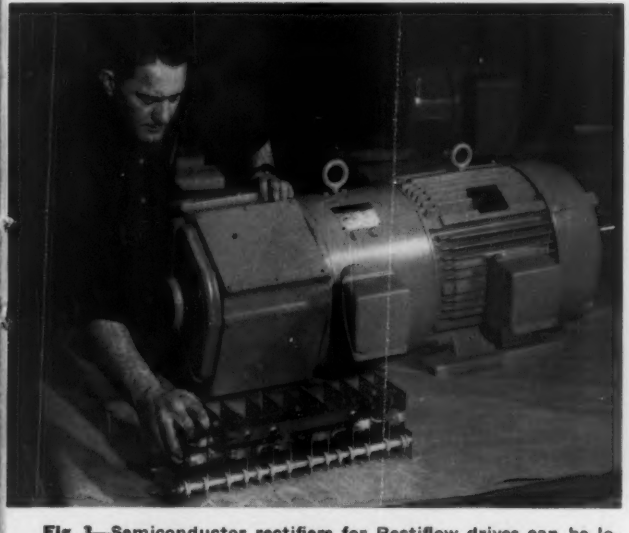


Fig. 3—Semiconductor rectifiers for Rectiflow drives can be located at any convenient site near the drive. Shown here is the silicon-rectifier bridge designed for use with the 15-hp unit.

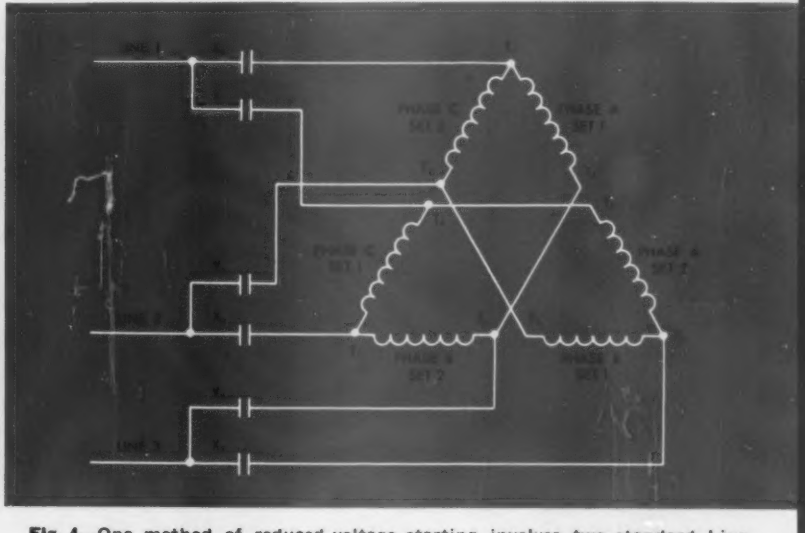


Fig. 4—One method of reduced-voltage starting involves two standard Line starters and a double-delta primary on the wound-rotor motor. By this scheme, a-c starting current is reduced by 50 percent, starting torque by 25 percent.

Consider now the operating characteristics of the Rectiflow drive, as shown in Fig. 5. The starting torque of Rectiflow drives is a maximum of 600 percent of full-load values when full line voltage is applied on the primary of the wound rotor and full field is applied to the d-c motor. Variations down to 25 percent of starting torque at starting can be obtained as described in the double-delta scheme.

Smooth starts are obtained by exciting the d-c field at the same time the a-c contactor is closed. The time constant of the d-c field allows a smooth build-up of torque, Fig. 6.

In the basic drive, the combined characteristics of the wound-rotor motor and the shunt-wound d-c motor afford inherent constant-horsepower characteristics. However, by proper use of certain d-c motor characteristics and selection of proper frame sizes, an economical and effective constant-torque drive is possible. In drives designed for constant torque, the torques developed by the two motors are cumulative on the common shaft. If load is increased at any preset speed within the unit's designed range the wound-rotor motor tends to slip. Since this increases the current in the d-c armature, it in turn increases the d-c torque. This characteristic gives stability under load. At synchronous speed of the wound-rotor motor, no voltage or current is available from the slip rings. Therefore, this feature and the fact that the motors are assembled on a common shaft will prevent the shunt-wound d-c motor from overspeed.

Rectiflow drives have been developed in 1½-to-1, 2-to-1, and 3-to-1 speed ranges, for both constant-horsepower and constant-torque applications. Units can be dripproof, force-ventilated, or totally enclosed fan cooled. Drives rated from 7½ horsepower to 75 horsepower are built as a unit frame, as will be drives in smaller ratings, now being considered. Above 75 horsepower, coupled units on a common bedplate are supplied. In building Rectiflow drives new materials and new manufacturing methods for new Life-Line A induction motors and Life-Line H d-c motors are consolidated in unitized equipment.

An interesting feature of construction is that the slip rings are mounted on the front end with the d-c commutator to give accessibility and ease of maintenance. The secondary currents are transmitted to the slip rings through enclosed machined slots in the shaft using the same design techniques and insulation system used on high-frequency generator sets.

Packaged Rectiflow drives are an entirely new all-electric system, in which the reliability, simplicity, and ease of maintenance result from use of well-tried electrical components. With these basic components a drive is obtained that will operate over the desired speed range with a speed regulation of approximately 7½ percent, and with an efficiency at full load over the entire speed range of 85 percent on 125-horsepower drives, and down to 80 percent on the smaller drives. The power factor is approximately the same as an a-c squirrel-cage motor, while the efficiency is approximately 5 percent lower. By the use of a series field on the motor, many desired speed-regulation curves from no load to full load can be obtained, as Figs. 5 and 6 show.

In cases where a low threading speed and dynamic braking are required, various methods are available. One such arrangement is shown in Fig. 7. In combination with magnetic-amplifier regulators, Rectiflow drives have been built with controlled accuracy of one-tenth of one percent. They are also suitable for electronic control of the d-c field current.

To summarize, Rectiflow drives have the following unusual and desirable characteristics: (1) they are suitable for any standard a-c voltage and frequency; (2) their maximum overload current is inherently limited by the wound-rotor induction motor; (3) they permit the use of rectifiers of small rating and compact size, since part of the mechanical power is supplied directly by the a-c motor; (4) the wound-rotor protects the rectifier from excessive currents, switching surges, and grounds; (5) they permit the use of standard a-c linestarters; (6) the characteristics of the wound-rotor induction motor and the d-c motor combine to give great flexibility; (7) they use standard a-c and d-c motor parts built into a single unit frame construction; and (8) the ability to control the speed of Rectiflow drive by adjusting the field current of the d-c motor permits the use of magnetic amplifiers and electronic control devices. ■

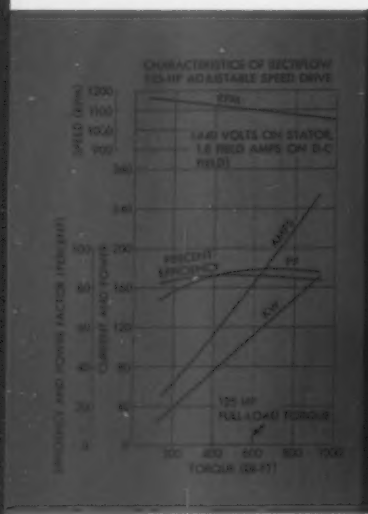


Fig. 5—Efficiency, power factor, speed, current, and power plotted against torque for a 125-hp Rectiflow adjustable-speed drive.

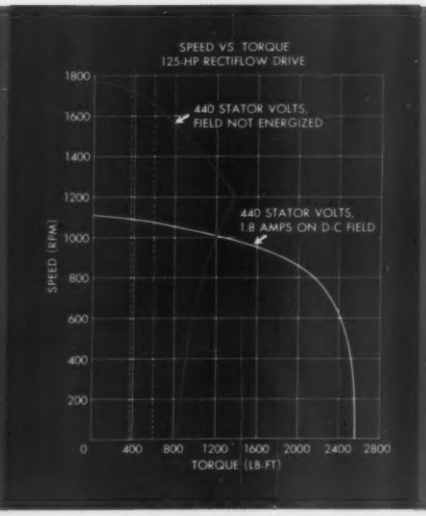


Fig. 6—By exciting the d-c field at the same time that the a-c contactor is closed, very smooth starts can be obtained. Time constant of the d-c field—apparent as difference between the two curves at start-up—allows smooth torque build-up.

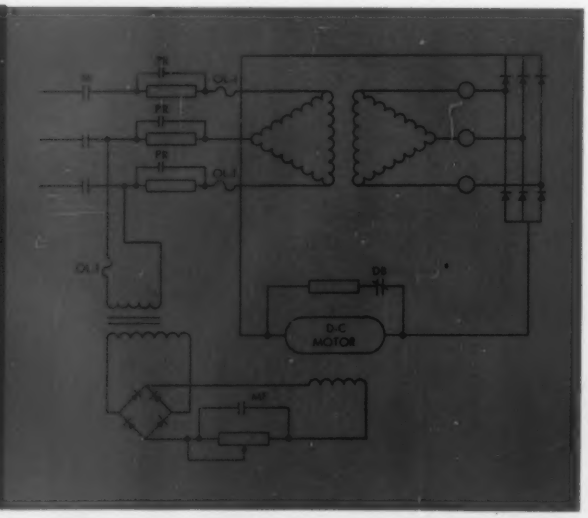
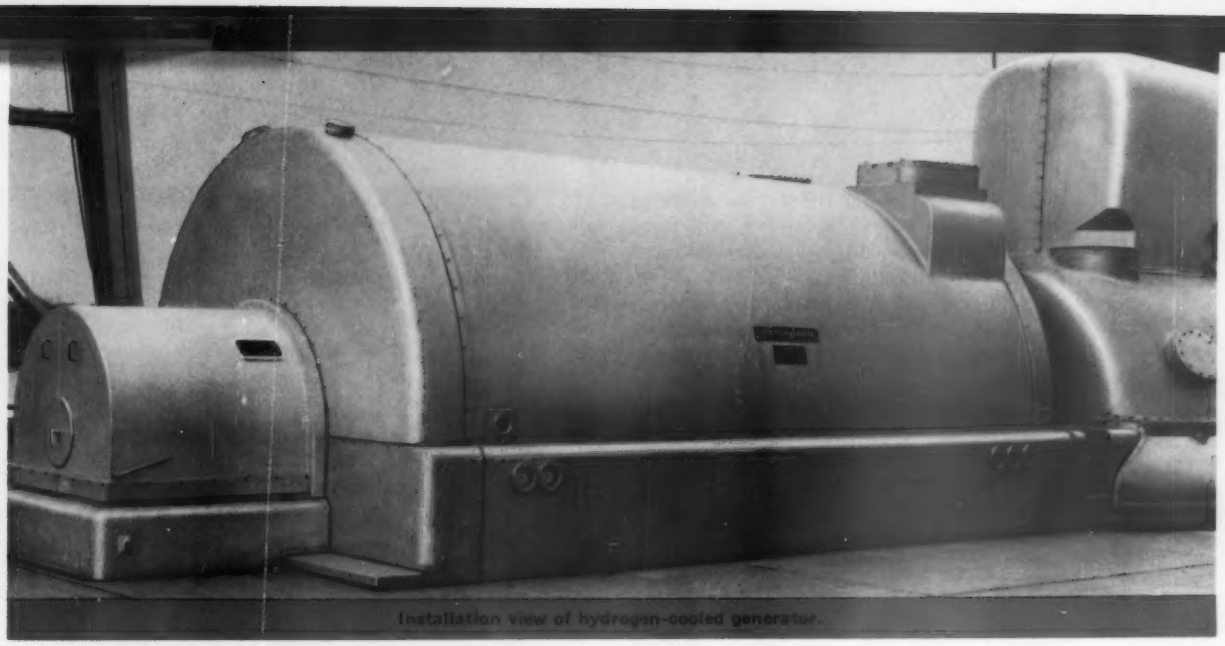


Fig. 7—A circuit for a Rectiflow drive in which dynamic braking and low threading speed are possible.



Installation view of hydrogen-cooled generator.

operation of hydrogen-cooled turbine generators

R. A. TOWNE, Turbine Generator Engineering, Westinghouse Electric Corporation, East Pittsburgh, Pennsylvania

Operation of hydrogen-cooled turbine generators with generator capability curves rather than by observable temperatures will assure safe operation.

The operation of hydrogen-cooled generators requires an appreciation of the significance of the observable temperatures in the various components of the unit. With the advent of elevated hydrogen pressures, the behavior of resistance temperature detectors embedded in the stator winding has become a function of both gas pressure and load. Consequently, the observable temperature indications obtained from hydrogen-cooled machines are not easily interpreted. Operators can be confused by the apparent paradox of an increase in load resulting in a decrease in temperature rise, provided gas pressure is increased at the same time. Another unexpected characteristic is brought to light by the behavior of cold-gas temperature. Many operators have learned, in operating older types of generators, that the so called ambient, or cold-gas temperature, should not exceed 40 degrees C under any condition of operation. They now find that this temperature cannot be maintained at the higher hydrogen pressures. Because of these idiosyncrasies, hydrogen-cooled generators cannot be operated successfully by means of observable temperatures, and it is therefore recommended that they be operated by means of *generator capability curves* to assure safe operation.

The capability of a hydrogen-cooled generator is limited by the hot-spot total temperatures and temperature rises in various elements of the construction, such as the stator-winding copper, rotor-winding copper, and stator iron. Any one of these temperatures can be the limiting factor, depending on load, power factor, or gas pressure carried on the machine. Generally, hot-spot temperatures cannot be measured directly, so that temperature must be measured at points as close as possible to the predicted hot spot. The difference between observed temperatures and the actual hot spot is a variable that is usually dependent on load, hydrogen pressure, and geometry of the particular design.

stator-winding temperature

The stator-winding temperature is measured by means of resistance temperature detectors (RTD). The stator RTD consists of a resistance coil (of 10 ohms resistance) embedded between the two armature coils in a stator slot. This arrangement is shown in Fig. 1. Usually, 12 resistance coils are dispersed through the winding to obtain representative maximum temperatures throughout the embedded portion of the winding. The detector is in contact with the outside surface of stator-coil insulation; therefore the indicated temperature is somewhat different from actual copper temperature.

In the case of conventionally cooled generators, all heat generated in the stator winding must flow through the insulation to reach the cooling hydrogen. As a result, temperature difference across the thickness of the insulation varies with load, and the temperature difference between the copper and the RTD varies correspondingly.

Hydrogen-cooled machines are rated so that copper temperatures remain approximately constant at the ratings corresponding to the various gas pressures. Therefore, the RTD will read a lower value at higher loads and gas pressures, since copper temperature is constant but temperature drop through the insulation is increased. This behavior results from the higher heat-transfer rate and lower gas-temperature rise of hydrogen at elevated pressures. The relative variation of the stator temperature is shown in Fig. 2a.

Inner-cooled turbine generators differ from conventionally cooled units in that ventilating hydrogen is passed through the interior of the stator winding, from one end of the winding

to the other, instead of passing over the outer surface of winding insulation. Heat flow is principally inward from stator copper to gas; the amount of heat flowing outward through winding insulation is relatively small. Actually, at low loads, heat flow may reverse in portions of stator windings since the ends of the windings where gas enters is cold, but the end where the gas leaves is hot. Because the hot spot is in the end turn of the winding, the usual location of the embedded RTD is far from the hot spot. Therefore, an RTD embedded in the central part of the stator winding is not a satisfactory indicator of stator winding hot spot on an inner-cooled machine. To obtain a more realistic indication of hot-spot temperature, a new device has been employed. A resistance coil is mounted in the stream of warm hydrogen discharged from the stator-winding vent ducts. The difference between the warm hydrogen and the stator-copper hot spot at the end of the winding is a consistent function of load and gas pressure. Thus, the discharge gas temperature is a more dependable indicator of copper temperature on an inner-cooled coil than the RTD embedded between the windings in the slot. Also, since the difference between gas temperature and hot-spot temperature is a function of load and gas pressure, this indication must be interpreted correctly to determine true hot-spot level of the unit under load (Fig. 2b).

The stator winding discharge gas temperature indicator on the inner-cooled stator coil has been shown to be similar in behavior to the embedded RTD in the stator windings of the conventionally cooled unit, in that the indication is a consistent function of the load and gas pressure on the machine; but proper interpretation of the temperature indication requires a consideration of the thermal characteristics of the particular design. Since such a consideration is impractical for the operator, another approach to the proper operation of a hydrogen-cooled machine is necessary. This approach is provided by the generator capability curve.

rotor-winding temperature

The rotor-winding average temperature is determined by measuring the total resistance of the winding itself. This measurement is direct, as compared to the indirect methods that must be used with the stator winding to avoid the hazards of high voltage. However, as in the case of the stator winding, the operating limitation of the rotor winding depends on its hot-spot temperature, and the difference between average temperature and hot-spot temperature is a function of both load and gas pressure. Thus the same problem exists here as for the RTD on the stator—the observable temperature differs from hot-spot temperature and is not directly measurable. This situation exists on both conventionally cooled and inner-cooled rotors. Again, the generator capability curve provides a means for operating without exceeding rotor capability.

stator-core temperature

During operation at leading power factors (underexcited operation), flux distribution in the generator is such that high losses occur in the first few inches of iron at the ends of the stator core. Under these circumstances, core temperature becomes the load-limiting factor, rather than stator- or rotor-winding temperatures. Generators expected to operate in this range are often equipped with thermocouples embedded in the ends of the core to provide an observable indication of core temperature. However, the majority of machines are not so equipped, and the operator has no direct method of operating. Again, the generator capability curve provides a

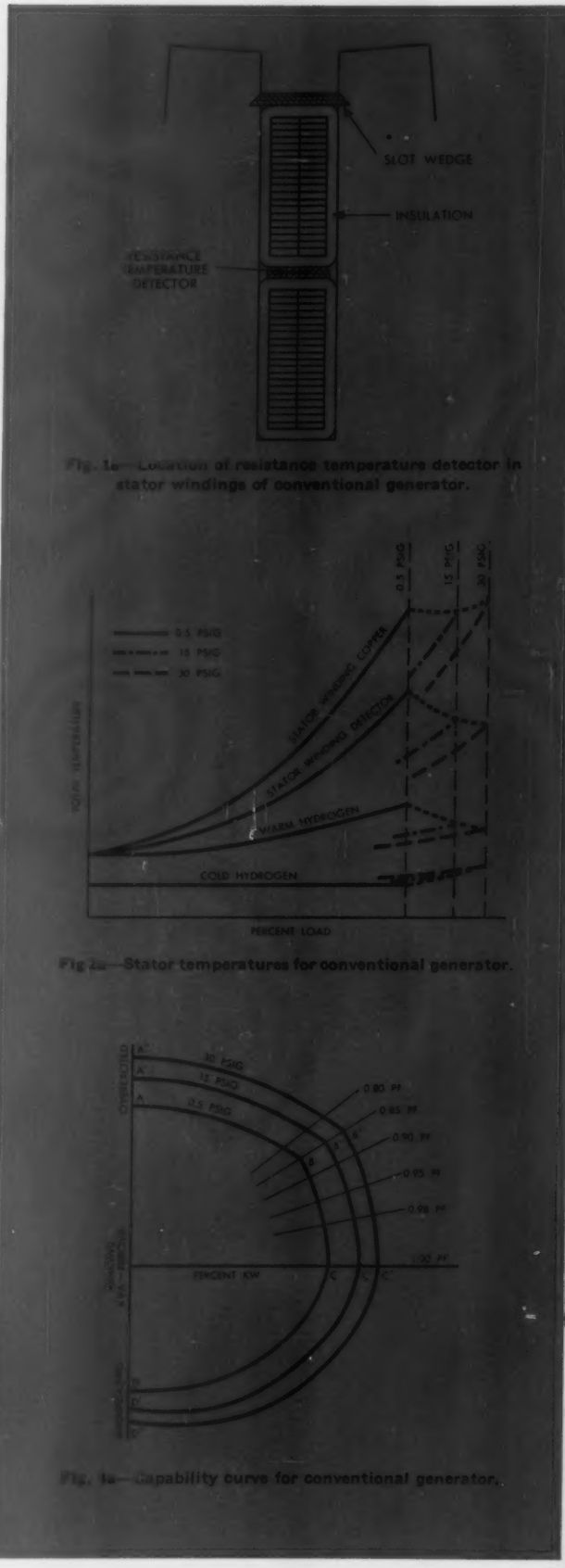


Fig. 1a—Location of resistance temperature detector in stator windings of conventional generator.

Fig 2a—Stator temperatures for conventional generator.

Fig. 1a—Capability curve for conventional generator.

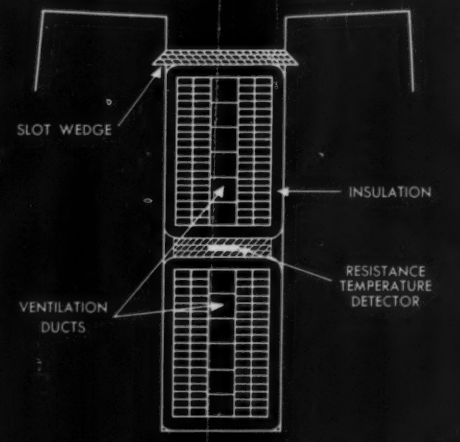


Fig. 1b—Location of resistance temperature detector in stator windings of inner-cooled generator.

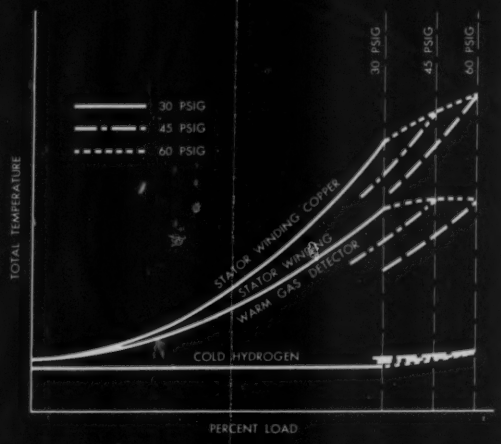


Fig. 2b—Stator temperatures for inner-cooled generator.

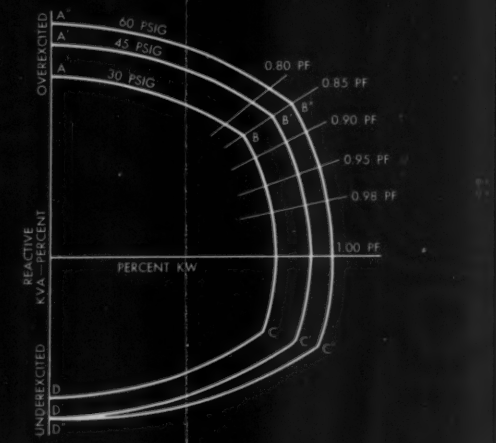


Fig. 3b—Capability curves for inner-cooled generator.

guide for limiting operation to safe stator core temperatures.

cold-gas temperature

Cold-gas temperature is determined by the ability of hydrogen coolers to absorb heat from hydrogen. The difference between average hydrogen temperature and average water temperature depends on the amount of heat to be absorbed. Thus, when the load is increased without changing the gas pressure, the temperature difference between gas and water must increase; assuming a constant supply of cold water at a fixed temperature, the cold-gas temperature will increase. If hydrogen gas pressure is increased with a corresponding load increase, the difference between average gas temperature and average water temperature remains practically constant, since the increased heat transfer rate (due to the higher gas pressure) almost exactly compensates for the increased generator losses. However, cold-gas temperature will increase because of the increased specific heat of hydrogen at increased gas pressure, and the corresponding reduction in gas-temperature rise. Hence, the old operating rule that the cold-gas temperature should not be allowed to exceed 40 degrees C does not hold true for hydrogen-cooled machines operated at elevated gas pressures.

Conventionally cooled generators are designed to have a cold-gas temperature of 40 degrees C or less at the 0.5 psig rate, with rated water conditions. The maximum cold-gas temperature for the standard gas pressures will be: 40 degrees C at 0.5 psig, 44 degrees at 15 psig, and 46 degrees at 30 psig. Corresponding cold-gas temperatures for inner-cooled units under standard conditions of load and cooler water flow are: 42 degrees C at 30 psig, 44 degrees at 45 psig, and 46 degrees at 60 psig. These values vary slightly with different designs. If water flow or temperature differs from contract values, cold-gas temperatures differ from the above values; but the variation will be in a similar pattern.

generator capability curves

Capability curves for typical conventional and inner-cooled turbine generators are shown in Figs. 3a and 3b. The curves are shown for each of the standard hydrogen pressures. These curves are drawn to limit hot-spot temperatures in the stator and rotor windings and in the stator core to practical operating values. These capabilities are determined by calculation and shop test, and are not directly determinable from the usual observed temperatures during operation.

Operation in the range between rated power factor and zero power factor overexcited is limited by rotor-winding temperature, and is defined by the portion of the curve lying between *A* and *B*. This curve gives operation with the field amperes constant at the nameplate value corresponding to the gas pressure under consideration. At the higher gas pressures, the improved cooling obtained makes operation at higher field currents permissible. The region between rated power factor (overexcited) and 100 percent power factor is limited by stator winding temperature, and is shown on the curve between *B* and *C*. Operation on this portion of the curve results in constant stator amperes. In this region, field current varies with load and power factor, but is always less than the maximum allowable value.

Operation underexcited at any power factor is limited by stator core temperature, and is shown between *C* and *D* on the capability curves. This portion of the curves is slightly different for conventionally-cooled and inner-cooled units due to a difference in the method of specifying ratings of these different types of machines. ■

WHAT'S NEW
. . . in engineering

inner-cooled transformer

The development of an "inner-cooled" transformer—a major advance in power-transformer design—makes possible transformers that can be smaller, lighter, and significantly higher in rating. Using conventional methods of design, three-phase transformers rated up to 380 mva have been built; with the new inner-cooled design, engineers foresee ratings up to about 600 mva.

In the new inner-cooled design, oil is circulated between the strands of parallel conductors that are at the same potential. Thus, oil ducts are eliminated between coils and windings. This permits use of materials having higher insulation strength than oil where voltage stresses occur. In this manner, smaller, lighter, and higher capacity units can be built with the same design margins as the conventional construction.

The first commercial unit of the new design (1) is being manufactured for the New York State Electric and Gas Corporation. The three-phase substation unit is rated 30/40/50 mva, 115 kv. Low voltage will be 34.5 kv. The transformer is in the 550-kv BIL insulation class. ■

1

2

submerged motors

The problems of designing motors to operate submerged in liquids have virtually been solved—but the problems are magnified when the liquid is high-octane airplane fuel and the motor must operate under varied pressure and climatic conditions in the fuel tank of an airplane.

Here, a motor-pump assembly is being raised into a test tank at the Westinghouse submersible-motor test facility (2). The upper part of this tank will be flooded with 165 gallons of high-octane airplane fuel to evaluate the performance of the motor while submerged and under simulated conditions of altitude, heat, or cold. ■

helicopter test stand

As helicopters grow in size and capacity, so does the equipment needed to test them. Indicative of this trend is a new helicopter main rotor head and blade test stand at Sikorsky Aircraft Division, United Aircraft Corporation; this stand is equipped with a 4000-hp, 120/270-rpm vertical d-c motor (3).

The test stand resembles a five-story-high inverted ice-cream

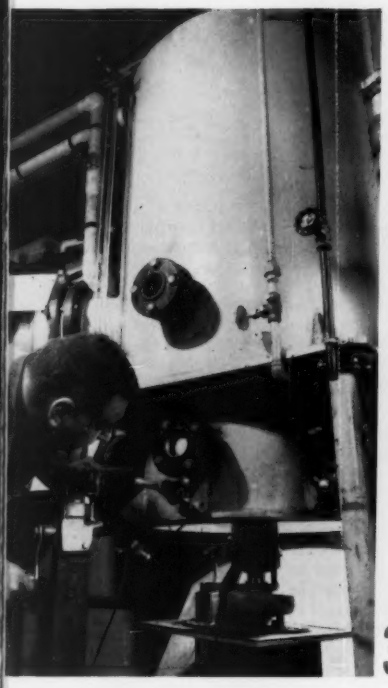
cone. The d-c drive motor is located at the base of the cone. The shaft extends up the center of the cone through torque- and thrust-measuring devices. The rotor head and blades to be tested are mounted on the end of this shaft. By means of test devices, various data can be collected.

The d-c motor is used instead of a gasoline engine because of simpler operating and maintenance problems, and—importantly—because of the fine speed control, down to zero speed, possible with such a motor.

Indicative of the trend in helicopters is the fact that while 4000 hp is undoubtedly adequate for many years to come, space has been left for a second 4000 hp to be mounted atop the present motor should the need arise. ■

transistorized radar indicator

A transistorized radar indicator, a repeater for search radars, has been developed for the U.S. Navy. Designated the AN/SPA-25 (XN-1), the plan position radar indicator features substantial savings in space and weight. This unit has been installed aboard U.S.S. *Norfolk* for operational evaluation.



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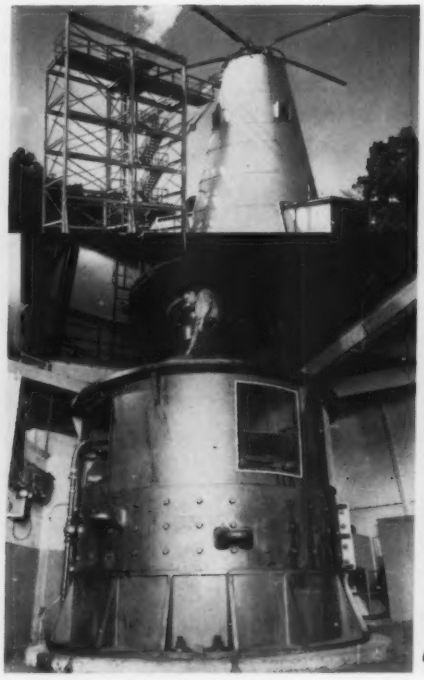


3

With self-contained power supply, the AN/SPA-25 (XN-1) contains 57 transistors, three vacuum tubes (exclusive of the cathode-ray tube) and seven magnetic amplifiers. The unit measures 17 inches high, 18 inches wide, and 28 inches deep; it requires less than five cubic feet of ship space. This represents a volume saving greater than two to one over conventional vacuum tube indicators. The total weight is less than 180 pounds. Input power requirements are standard (115 V, single phase, 60 cps). Power consumption is 236 watts, much lower than conventional plan position indicators which use about 1000 watts.

Problems of mechanical packaging, inherent with design goals of small size and light weight, were resolved through the use of dip-soldered printed-circuit boards. These printed-circuit boards are fitted with plug-in connectors and positioned on the top and sides of the indicator main frame for quick access.

The AN/SPA-25 (XN-1) operator can select intelligence from any one of eight radars for presentation of targets out to 300 nautical miles. The range scale is continuously variable down to four nautical miles, the lower range for navigational operation. A range ring circuit, capable of displaying range rings at 1, 2, 5, 10, 25, and 50 nautical miles, is supplemented by a range strobe and an operator time shared cursor to facilitate range and azimuth readings. The range rings are accurate to within two degrees. One percent linearity has been achieved.

nuclear pellets for reactors

Hundreds of nuclear fuel pellets—each one approximately the size of the filter tip on a cigarette—arranged in the proper pattern and quantity make up an atomic fuel that will generate and sustain the nuclear fission process in atomic reactors.

The first step in producing fuel pellets is the mixing of a slurry composed of uranium oxide and organic binders. These ingredients are blended in a king-size electric mixer similar to that used in the home.

The next step, after the slurry has been dried and the powder suitably prepared, is to feed the mixture into a special automatic press which compacts the powder into "preforms" that do not crumble easily (4). A plastic shield confines uranium powder to the immediate area of the press. The pellets are then placed in special pans and sintered in a high-temperature sintering furnace. This sintering operation removes all organic material and strengthens the bonding force within the pellet itself.

4

After sintering, the pellets are transferred to various grinding machines to achieve the desired final dimensions. Rigid quality control specifications are maintained since each pellet must meet tolerances less than one-thousandth of an inch.

In use, the pellets are inserted into a slim, stainless steel tube. A number of the tiny fuel cylinders are packed end-to-end inside the entire vertical length of the rod, and the top is sealed by welding. When loaded, the stainless container is ready for use as part of a fuel element in an atomic reactor. ■

predesigned super alloy

A new predesigned super alloy that exhibits outstanding strength at the white-hot operating temperatures found in rockets, missiles, and jet engines has been developed by Westinghouse scientists. The alloy, named Nicrotung, is expected to raise the operating temperatures of jet-engine turbine blades to 1800 degrees F. This is a temperature boost of about 150 degrees over present day engines and about equals the total increase in operat-

ing temperatures made in such engines over the past five years. Such increases in operating temperatures make possible lighter, more efficient, more powerful engines—and faster, better performing jet aircraft.

Nicrotung gets its name from three of the essential metals that compose it—nickel, chromium, and tungsten. Nickel was chosen as the base element in the design of Nicrotung because it is the most practical high-melting-point element presently available for 1800-degree service. To this element, chromium was added to give oxidation resistance. And to this solid solution, a larger atom, in this case tungsten, was added to confer hardening. Some five additional metallic elements were introduced in varying proportions to enhance the basic properties already established. The result is an alloy that meets the physical and chemical properties prior calculations had predicted.

The breaking strength of the new high-temperature alloy at room temperatures is about equal to that of a good grade of structural steel. However, at the near-white-hot temperature of 1700 degrees F, Nicrotung withstands a stress of 32 000 psi for as long as 100 hours without failure. At 1800 degrees F, the alloy withstands a stress of 22 000 psi for this length of time. In contrast, structural steel would have less than one percent of Nicrotung's strength at these temperatures.

Nicrotung is another practical outcome of the unique Westinghouse research approach to materials development. Materials are predesigned from basic theoretical information rather than employing laborious and time-consuming cut-and-try methods. This new approach has brought important advances in magnetic, electrical, and high-temperature materials.

Although Nicrotung is still in its initial stages of development as a high-temperature alloy, it has looked outstanding in the basic requirements of a superior 1800-degree turbine blade material. Among these requirements are: castability, the ability to be cast into intricate shapes; oxidation resistance, the ability to resist chemical attack by the white-hot, high-pressure gases it encounters; stress-rupture strength, the ability to resist being pulled apart; and ductility, the ability to give under stress without shattering. An alloy in its initial stages of development seldom meets as many requirements of its ultimate application as Nicrotung has thus far demonstrated.

The alloy has been prepared on a pilot-plant scale, and is undergoing exhaustive tests to evaluate it for use in jet engines. ■

new series of power transistors

A new series of silicon transistors can operate in the power range. These devices were made possible by ultrapure silicon, coupled with new device fabrication techniques. Two specific types of n-p-n fused-junction transistors have been produced—a 2–5 ampere unit can handle power up to 1 kw, and a 10–20 ampere unit handles power up to 3 kw.

2–5 AMPERE SILICON POWER TRANSISTORS

These silicon power transistors have emitter-to-collector voltages of 50 to over 300 volts. Current ratings on these units range from 2 to 5 amperes—based on the current at which current gain is equal or greater than 10.

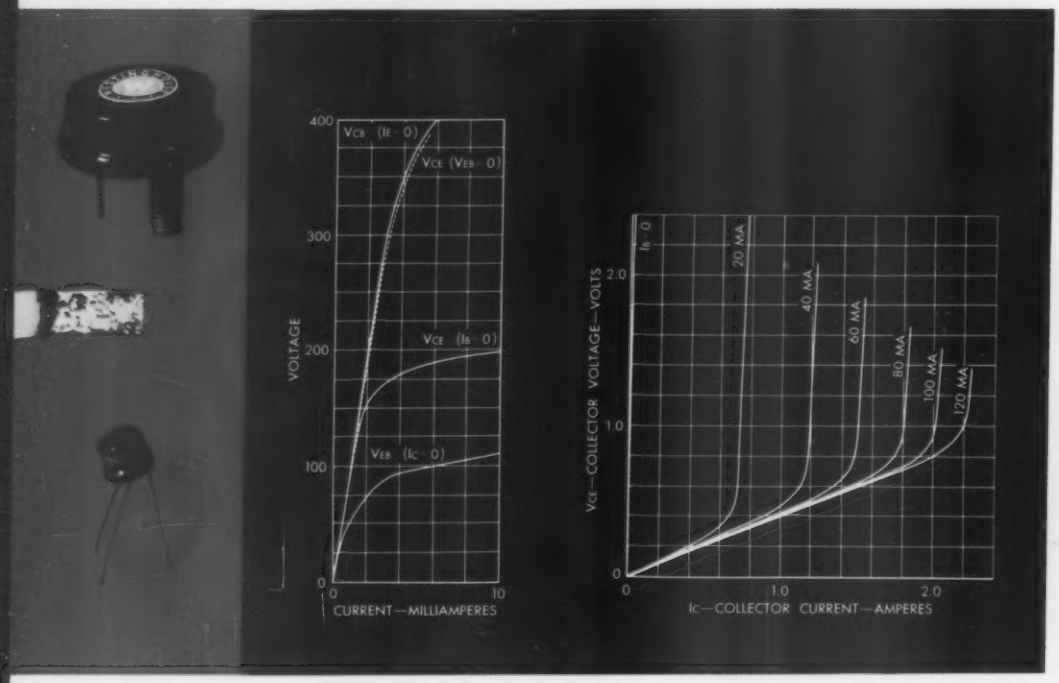
These high voltages and currents, coupled with low saturation resistances, permit the use of these devices for high-power switching operations with high efficiencies. For example, as a d-c switch handling one kw (200 volts at 5 amperes), the internal dissipation of the units is about 5 watts with a resulting efficiency of 99.5 percent. Reverse leakage ranges from 2 to 3 milliamperes.

Because of the small case-to-junction temperature rise in switch operation, the silicon transistor can be used at temperatures up to limits imposed by the silicon material itself. In the 1-kw switch illustration, the case-to-junction rise is 2.5 degrees C.

10–20 AMPERE SILICON POWER TRANSISTOR

The principles and techniques used in developing the 2–5 ampere transistor have been extended to produce a device capable of handling up to 3 kw. Voltage ratings (collector-to-emitter) on present 10–20 ampere units range from 50 to 150 volts. Development work should increase the voltage rating to 300 volts. As on 2–5 ampere devices, current ratings are specified at a current gain of 10 amperes. Used as a d-c switch, the 10–20 ampere transistor handles 3 kw with internal losses of less than 20 watts.

The encapsulation cases for both the 2–5 and 10–20 ampere silicon power transistors are designed with a screw stud to permit bolting to heat sinks in operation where heat dissipation is set by the operating condition. ■



The basic silicon power transistor is shown compared to a conventional low-power computer transistor.

Curves showing collector-base, collector-emitter, and emitter-base voltages of the Westinghouse 2–5 ampere silicon power transistor in the 300-volt rating. These voltages are 3 to 4 times higher than those of other present silicon power transistors.

Curves showing the output characteristic of the 2–5 ampere silicon power transistor in the common emitter connection. Here the saturation resistance at 2 amperes is 0.4 ohm. Current gain at 2 amperes is 20.

When the transistor was introduced, power-line carrier designers saw many possible advantages to applying the device to carrier apparatus. In 1952 **E. E. SCHENEMAN** was assigned to the original Company task force to develop transistorized circuitry for power-line carrier application. Since then, the greater portion of his work has been with transistors. He has several patents in this field, and was project engineer for development of transistorized carrier equipment, of which he writes in this issue.

Scheneman began college at Colorado University, later transferred to the University of Tennessee, where he obtained his BSEE in 1944. He joined Westinghouse on the Graduate Student Course, and was subsequently assigned to the power-line carrier section of the Electronics Division. He is presently a Senior Design Engineer in the microwave design section.

Scheneman's favorite hobby is traveling. Up to date, he has visited all states except two—and has also found time to see parts of Canada, Mexico, Cuba, and El Salvador.

A. E. VOYSEY and **R. L. WITZKE** arrived in nuclear power work by different routes, but at nearly the same time. Al Voysey, a native of Boston, first worked for Westinghouse as an apprentice machinist, but "retired" shortly to earn a BS in ME from the University of Delaware in 1930. He returned to Westinghouse in 1933 at the steam division, where he worked on marine auxiliary equipment. In 1942 he took military leave, but returned to Westinghouse in 1946 at the Sturtevant division, where he worked on turbines, blowers, and Precipitrons. In 1951, he joined the relatively young Atomic Power Division, where he subsequently managed several phases of government nuclear work. In 1956, Voysey transferred to commercial atomic power activities, now known as the Atomic Power Department. His present responsibility is for Large Plant Engineering, including the nuclear steam generator for the Yankee plant.

Ray Witzke, on the other hand, joined the electric-utility engineering department immediately after his graduation from the State University of Iowa, where he had earned his BS in EE in 1934 and his MS in 1936. For several years he worked on the development of the Westinghouse analog computer. In 1939 he was assigned responsibility for electric-utility applications on the West Coast and in New England. In 1952 Witzke organized and was placed in charge of the Atomic Power Study Group, where he was responsible for the evaluation of reactor types for power production. When this activity expanded in 1954 he became manager of the plant section, and subsequently manager of the application engineering department.

T. R. SPECHT attended the University of Minnesota, graduating with a BEE in 1940. In 1951 he added to this an MS degree from the University of Pittsburgh. Specht began his engineering career in 1940 designing motors and generators, but after only three months of this he left to work in an Air Force radio laboratory. This job was also short-lived; after four months at the laboratory, Specht decided upon transformer engineering. This decision was the right one; transformer engineering was his forte. He settled down in the transformer design section of the Transformer Division. Here he took part in developing the current transductor, linear coupler, and the biased current transformer.

In 1949 he was transferred to the development section of the general transformer engineering division. The development section was later enlarged and called the long range major development (LRMD) section, where Specht presently works as a Fellow engineer. Specht now divides his time between transformer noise "sleuthing" and magnetic-materials studies. In addition to his job as secretary of the Sharon, Pennsylvania section of the AIEE, he finds time for the working group of the Transformer Audible Sound Committee. He has written four articles on the subject of transformer sound, including a description of the power transformer sound room (anechoic chamber), which he took an active part in planning and engineering.

Since coming with Westinghouse in 1941, **W. H. MORSE** has spent most of his time wrestling with mechanical design problems of large a-c motors and generators. Morse came on the Graduate Student Course with a BSME from Lehigh University, and went directly to the mechanical engineering section of the a-c engineering department. In 1950, he was made manager of the section. When the Large Rotating Apparatus Department was established in 1957, Morse became manager of a-c motor and generator engineering, his present position. It was here that Morse helped direct the team that developed the new F/A motor, which he describes in this issue.

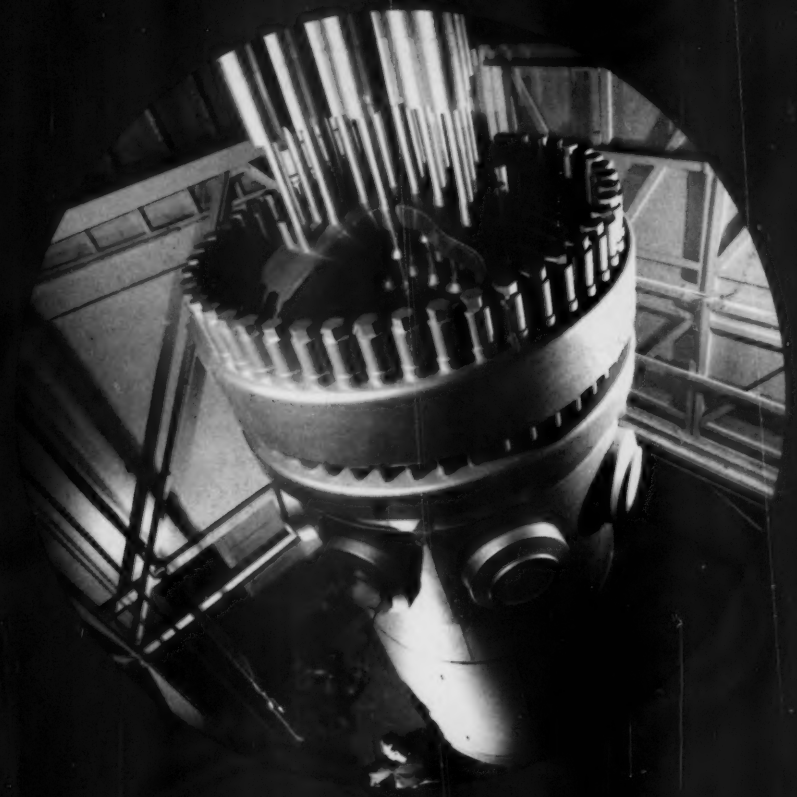
Morse has two recreations, and does well at both. He plays golf in the 70's, and up until recently was a member of the Westinghouse team in the Pittsburgh Industrial Bridge League.

In reminiscing about his 38 years with Westinghouse, **W. R. HARDING** remembers most clearly those developments that were accomplished in an extremely short period of time through the utmost in cooperation between engineering, manufacturing, and sales. For example, he recalls helping to develop the first Westinghouse high-voltage d-c generator for radio transmission. The order was for a 2000-volt, 1½-kw unit. It was received on a Monday morning. One week later the generator had been designed, built, tested, and shipped. Interestingly, this unit turned out to be the prototype of 3600 similar units built per year during World War II. Harding can cite many similar examples, including the design and construction of the motors for the early electric torpedos; five samples of these motors and their controls were developed and shipped in less than two months. This same design was used for nearly all the electric torpedos built during World War II—the total rated horsepower of the units of this particular design was over one million.

Another thing about Harding stands out to anyone reviewing his career—he's no "single track" designer. Included among his approximately 50 patents are an automatic welding head, motors for electric torpedos, arc welders, spot welders, variable-voltage elevator and planer equipment, automatic feeds for punch presses, and several for Rototrol rotating regulators. For those on the feed and planer equipment, Harding received the Company's meritorious patent award in 1940.

Harding, a native of North Carolina, graduated from the University of North Carolina in 1915, with a physics major and a math minor. For a year he taught high school in his home state, and then returned to the University and became an instructor in physics; during this time he also completed his senior work in electrical engineering. He started on the Graduate Student Course in June of 1917, but joined the Army that August. In 1918 he returned to Westinghouse, and finished the engineering and design schools under B. G. Lamme, before being assigned to d-c motor engineering. Interestingly, one of Harding's two sons was later to be the recipient of the B. G. Lamme scholarship.

Harding became section manager of the d-c section in 1939, later became assistant manager of d-c engineering and is now assistant manager of all motor engineering in the Motor Department. If space permitted, many interesting stories of Harding's work at Westinghouse could be told. Suffice it to say, however, that it has been marked by imagination, creative effort, and the ability to work with others.

R. A. TOWNE came directly to Westinghouse with a BSEE from the Clarkson College of Technology in 1944. From the Graduate Student Course, he went to the turbine-generator test floor, and then into the turbine-generator engineering department. Towne's only break with turbine generator engineering came in 1950, when he decided to give farming a try. But in three months, he was back designing turbine generators, and has stayed there since.

Besides farming, Towne has another love, which at one time almost lured him away from engineering. From the time Towne started college, he has worked as a pianist for society dance bands. He worked his way through school with his piano, and at that time seriously considered staying a musician. He has continued as a part-time musician, and only recently decided to retire. For the moment, the engineering profession has him all to itself.